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US005801707A

United States Patent [19]
Rolnik et al.

[11] Patent Number: 5,801,707
[45] Date of Patent: Sep. 1, 1998

[54] METHOD AND APPARATUS FOR
DISPLAYING HIERARCHICAL DATA
ASSOCIATED WITH COMPONENTS OF A
SYSTEM

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Assistant Examiner—Cliff N. Vo

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[57] ABSTRACT

[21] Appl. No.: 684,599

A method of displaying hierarchical data. The method includes the steps of: retrieving hierarchical network data and displaying the hierarchical network data using a perspective three dimensional view. The hierarchical data includes a plurality of data elements. Each data element is associated with a network device. An apparatus for displaying hierarchical data is provided. The apparatus comprises a display device, a memory device storing the hierarchical data, and a processor responsive to the memory. The processor includes a graphical display module that displays the hierarchical network data using a perspective three dimensional view. The hierarchical data includes a plurality of data elements where each data element is associated with a network device;

[22] Filed: Jul. 19, 1996

[51] Int. Cl. 6 G06F 13/00

[52] U.S. Cl. 345/429

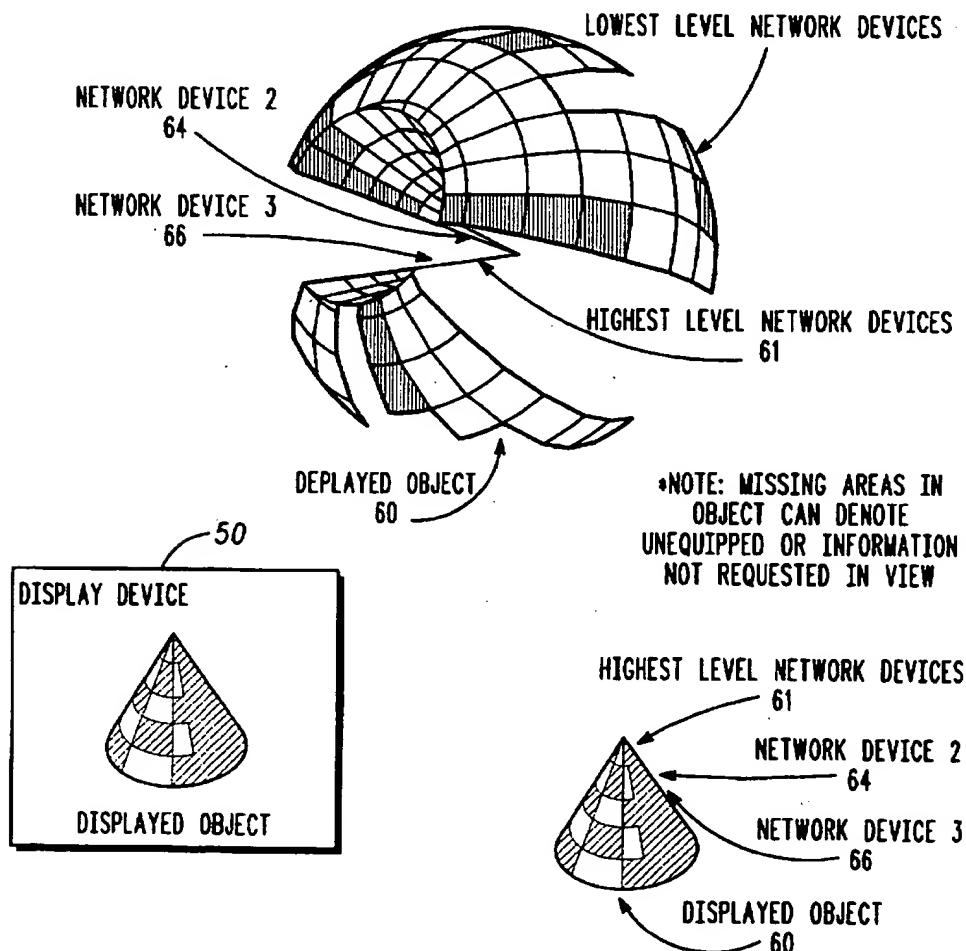
[58] Field of Search 395/329, 330,
395/333, 331, 118, 355, 356, 357

[56] References Cited

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15 Claims, 4 Drawing Sheets



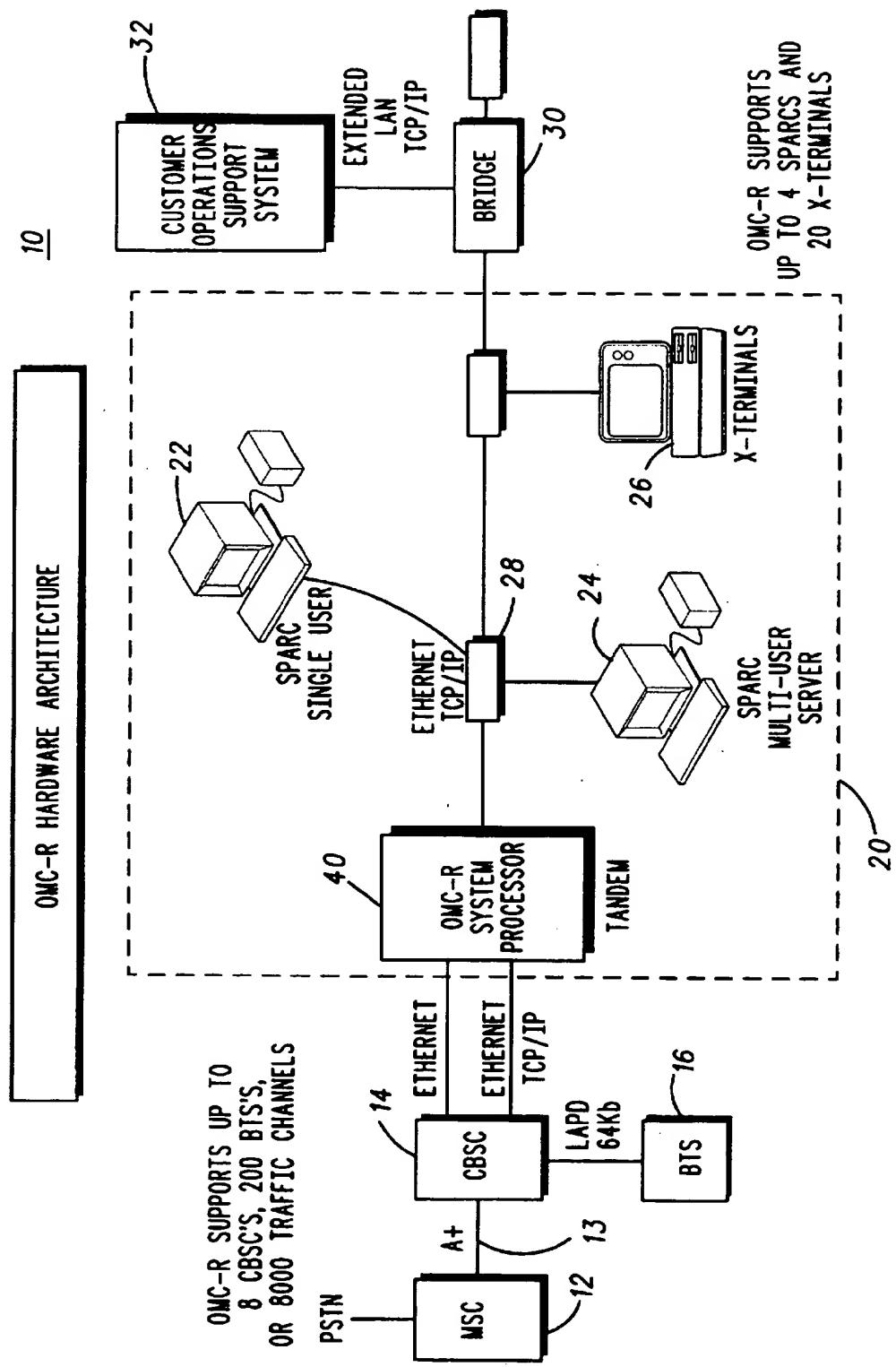


FIG. 1

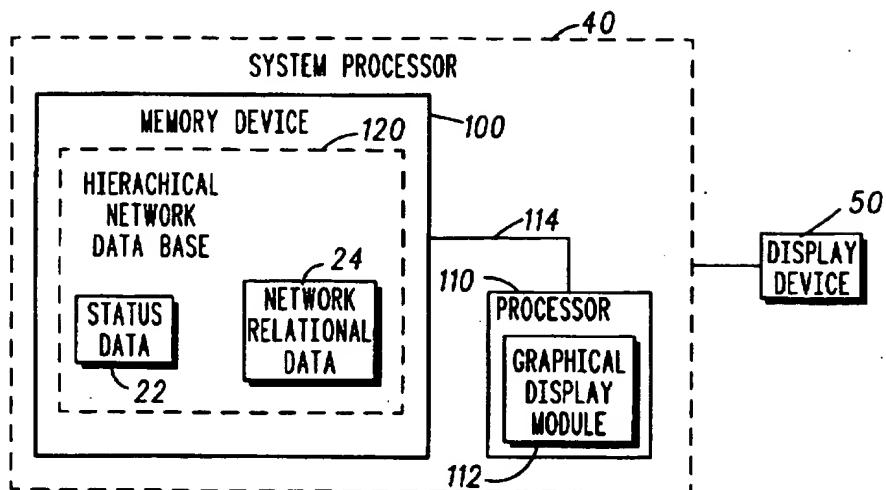
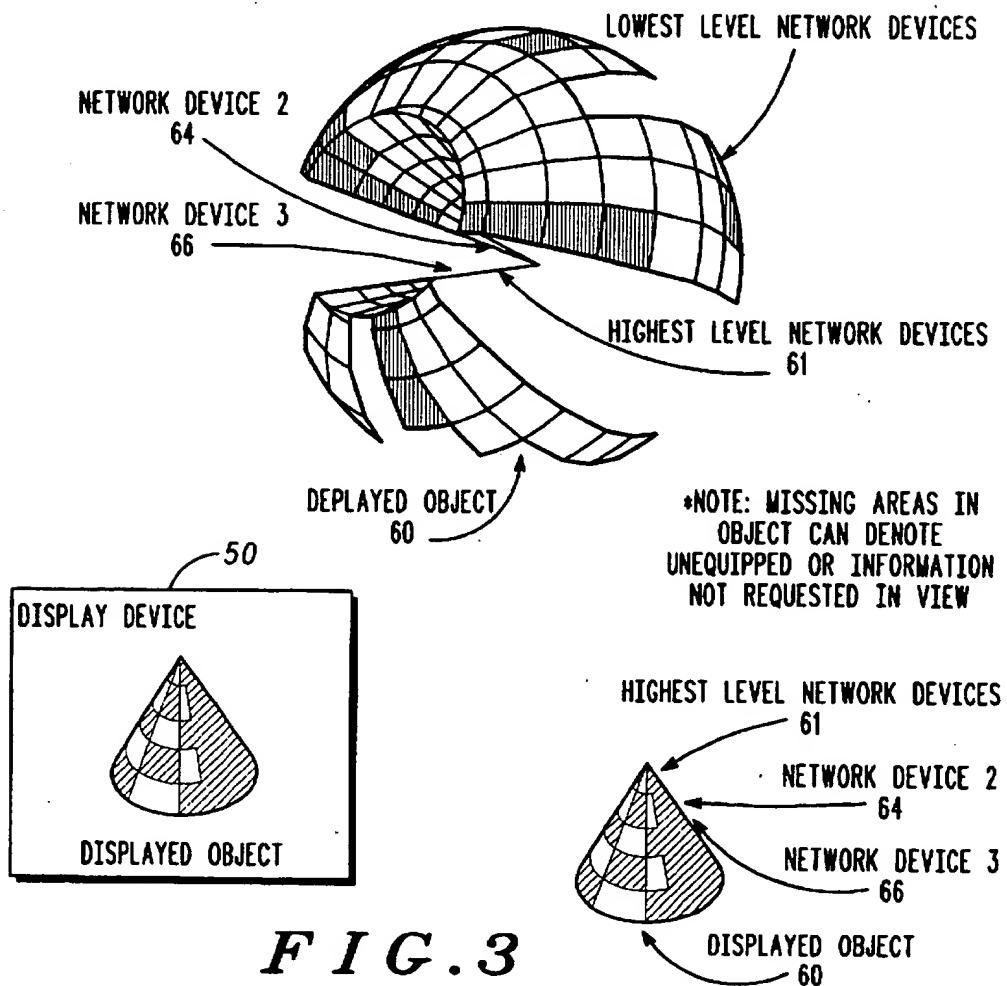


FIG. 2



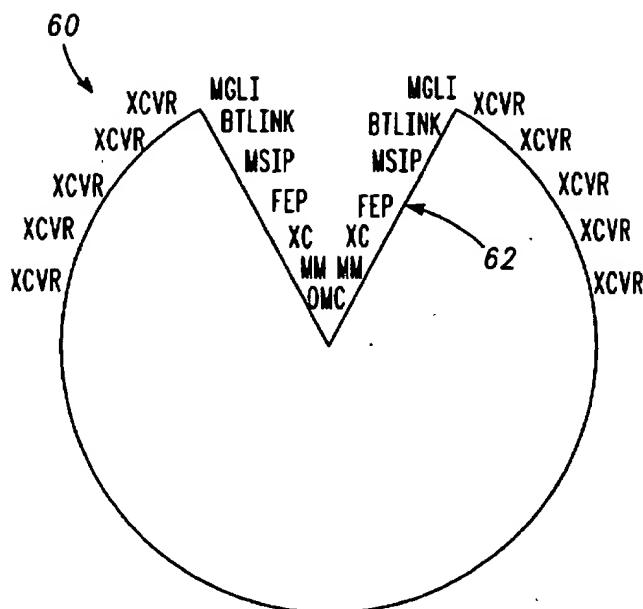


FIG. 4

EXAMPLE OBJECT REPRESENTING A DATA ELEMENT PRESENTED IN THE DISPLAY

DEVICE TYPE	ID1	ID2	ID3	ID4	ID5	PLATFORM	TELECOM STATUS
							VALUE

ABSTRACT CLASS LOGICAL DEVICE

{

```

RC  INT  DEVTYPE;  ## THE DEVICE TYPE
RC  INT  ID1;  ## HIERARCHY INFORMATION
RC  INT  ID2;  ## HIERARCHY INFORMATION
RC  INT  ID3;  ## HIERARCHY INFORMATION
RC  INT  ID4;  ## HIERARCHY INFORMATION
RC  INT  ID5;  ## HIERARCHY INFORMATION
RC  INT  PLATFORM;  ## TELECOM PLATFORM
RW  INT  TELSTATUS;  ## TELECOM STATUS

```

// OPERATIONS

```

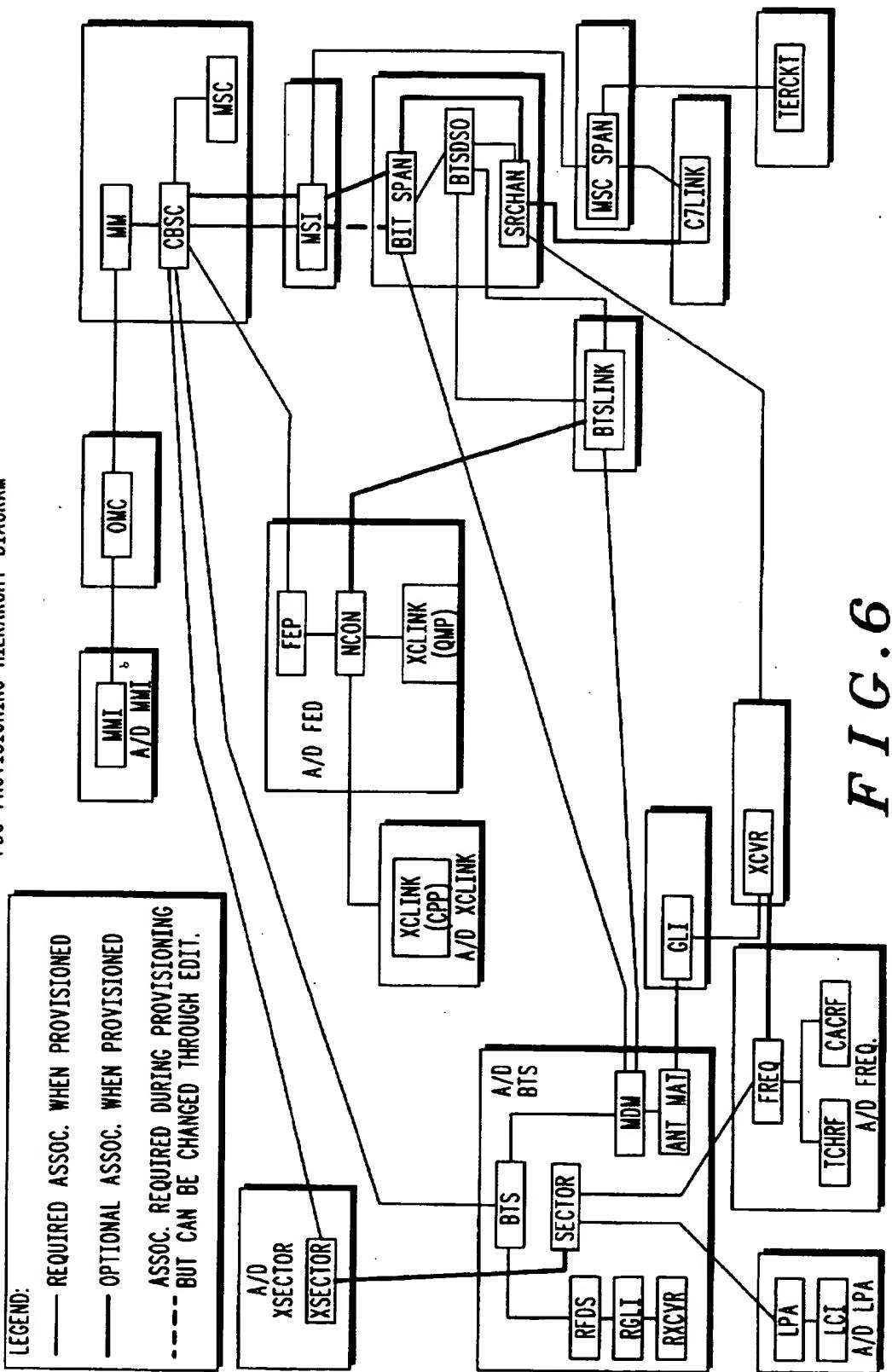
CONTROLLER Status Update (IN INT aNewTelphonyStatus);
CONTROLLER StatusReport(out int CuTelphonyStatus);

```

;

FIG. 5

PDC PROVISIONING HIERARCHY DIAGRAM



**METHOD AND APPARATUS FOR
DISPLAYING HIERARCHICAL DATA
ASSOCIATED WITH COMPONENTS OF A
SYSTEM**

FIELD OF THE INVENTION

This invention relates generally to complex systems, and more particularly to displaying hierarchical data associated with components of such systems.

BACKGROUND OF THE INVENTION

Complex systems with many components, such as cellular systems, generally require a high degree of maintenance. In order to manage the maintenance of each of the components, an operations center with a display representing various status indicators of the components is usually provided. Conventional systems typically generate reports such as alarm or traffic reports to provide system operators information regarding the operation of the system. Although these reports provide valuable information regarding specific aspects of the system, they fail to adequately provide an overall view of the system. More recently, improved display devices and operations centers use graphical user interfaces. Such graphical user interfaces typically display two-dimensional geographical information, such as a cell site view for a cellular communication system. However, due to the increased complexity of modern communication systems, there is still a need to display a high level view of the entire system. Such a high level view would allow trouble spots to be more quickly detected and acted upon.

Accordingly, there is a need for an improved method and apparatus for displaying data associated with components of a complex system.

SUMMARY OF THE INVENTION

In order to address this need, the present invention provides a method of displaying hierarchical data. The method includes the steps of retrieving hierarchical network data and displaying the hierarchical network data using a perspective three dimensional view. The hierarchical data includes a plurality of data elements where each data element is associated with a network device.

In accordance with another aspect of the invention, an apparatus for displaying hierarchical data is provided. The apparatus comprises a display device, a memory device storing the hierarchical data, and a processor responsive to the memory. The processor includes a graphical display module that displays the hierarchical network data using a perspective three dimensional view. The hierarchical data includes a plurality of data elements where each data element is associated with a network device.

The invention itself, together with its intended advantages will best be understood by reference to the following detailed description, taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram depicting a cellular system that may use an embodiment of the present invention.

FIG. 2 is a block diagram of the system processor and display device of FIG. 1.

FIG. 3 and FIG. 4 are diagrams of an object displayed by the display device of FIG. 2.

FIG. 5 is a diagram of a hierarchical data element definition used by the objects in FIGS. 3 and 4.

FIG. 6 is a diagram of a hierarchical network that may be displayed by the object of FIGS. 3 and 4.

**DETAILED DESCRIPTION OF THE
PREFERRED EMBODIMENTS**

Referring to FIG. 1, a communication system 10 including a plurality of components is illustrated. Communication system 10 is a cellular communication system including a mobile switching center (MSC) 12, a base station controller (CBSC) 14, an operation maintenance center (OMC) 20, an operation support center 32, and a plurality of base transceiver stations (BTS) 16. Each of the plurality of base transceiver stations 16 is connected to the CBSC 14 via a data interface known to those of ordinary skill in the art. Similarly the MSC 12 is coupled to the CBSC 14 via a conventional cellular interface 13, such as the A plus interface. The CBSC 14 is connected to the OMC 20 via a data connection such as a TCP/IP connection. The OMC 20 is connected to the operation support system 32 via bridge 30 and via a data network such as a TCP/IP local area network. The OMC 20 includes a system processor 40, a user station 22, a multi-user station 24, a display terminal 26, and a computer network interconnection system 28. The computer network interconnection system 28 is typically a standard computer data network such as a TCP/IP ethernet network. Although both a single user station and a multi user server 22 and 24, are shown, these servers are optional.

Referring to FIG. 2, a more detailed diagram of the system processor 40 is provided. The system processor 40 includes a memory device 100 and a processor 110. The memory device 100 is coupled to the processor 110 via a bus 114. The memory device 100 includes a hierarchical network database 120 which further includes a status data memory area 122 and a network relationship data area 124. The processor 110 includes a three dimensional graphical display module 112.

In the preferred embodiment, the display module 112 includes hardware and software necessary to present the hierarchical data to the graphical display. Examples of suitable software for the display modules 112 include three dimension rendering software available from Alias/Wavefront, Virtual reality modeling language (VRML), and HTML/JAVA®. JAVA® is a registered trademark of Sun Microsystems, Inc. Each of these software packages are known to those of ordinary skill in the art. Suitable hardware includes a high speed graphics monitor capable of quick three dimensional rendering which are known to those skill in the art.

The system processor 40 is connected to a display device 50 in a conventional manner. The display device 50 may be used as the display 26 within the OMC 20 or may be incorporated or attached to the operation support system 32. In any event, the display device 50 is used by operations personnel such as technicians, to control and maintain the communication system 10.

The hierarchical network data base 120, including both the status data area 122 and the network relationship data area 124, contains specific information regarding each of the components within the communication system 10. For example, many components within the base stations 16 such as transceivers, may each have an entry within the hierarchical data base 120. In addition, since each component in the communication system 10 is typically connected to one or more other components, the relationship between components is stored in the network relationship data area 124. For example, since BTS 16 is coupled to CBSC 14 a network

relationship between the BTS 16 and CBSC 14 would be stored in the network relationship data area 124. In this manner data regarding each component in the system 10 as well as the relationship between components in a hierarchical model may be stored within the hierarchical network data base 120.

Referring to FIG. 6, an example of a hierarchical network that may be implemented with a suitable database that stores the network. Many such databases are known to those of ordinary skill in the art. For illustrative purposes, an example of a database record for one element of information for one device in such a database is shown in FIG. 5. The particular database record of FIG. 5 describes the telephony status for a particular device in a cellular system.

Referring to FIG. 3, an example of an object shown on display device 50 via a three dimensional perspective view is illustrated. The display device 50 shows a displayed object 60 which preferably has a three dimensional shape. A plurality of network devices 62, 64, 66 are each represented by different regions on the surface of the displayed object 60. In addition, relationships between network devices may be shown on the displayed object 60, such as by having higher level network devices 61 displayed on an inner region of the displayed object 60. Although the displayed object 60 is shown to be stationary, it is contemplated that the displayed object may be rotated in any direction by command of an operator such that the operator may view the entire surface of the displayed object 60. In this manner, a greater number of network devices and their associated relationships with other network devices may be quickly seen at a high level. In addition to showing each network device, information associated with each network device may be displayed on the surface of the displayed object 60. For example, a status indicator of each network device may be shown via a different color on the surface region for each respective network device. For example, an out of service network device may be shown in red, an in service device may be shown in blue, and a device that has not been provisioned may be shown in green. Another method of displaying information regarding each network device would be to use a flashing indicator to display alarm conditions.

Referring to FIG. 4, a particular exemplary displayed object for a cellular communication system is illustrated. The displayed object 60 has a spherical shape, only a cross sectional slice of the sphere is shown in FIG. 4, and includes a plurality of network devices, which in this particular case are transceivers, on the outside surface of the object 60. On the inner surface, which is conical in this particular example, a plurality of higher level hierarchical related network devices associated with the transceivers at the surface are shown. For example, in the cellular communication system, the OMC 20 is a high level network device and is positioned in the core of the conical area 62. Other network devices in the system 10 are positioned above OMC 20 in a concentric fashion. For example, other network devices include mobility managers labeled MM, transcoders labeled XC, which are typically found within CBSC 14, a front end processor (FEP), a multiple span line interface processor (MSIP), a BTS link such as the link between-BTS-16-and-CBSC 14, and a master group line interface (MGLI).

All of the transceivers which would be found in a particular BTS 16 are preferably arranged in a vertical segment that extends along a longitudinal line over the surface of the displayed object 60. In this manner, an operator may immediately know which transceivers are associated with a particular BTS 16. Where the displayed device 50 is a conven-

tional resolution display, such as a CRT, it is contemplated that up to 750 transceivers may be illustrated. However, it is preferred to use a high resolution display, such as a 1280 by 1024 pixel display, so that several thousand transceivers may be viewed. In addition to the display of status information, the display system allows an operator to select one or more of the displayed network target devices, such as a particular transceiver, by clicking on the surface area associated with that transceiver, such as by using a computer mouse. After a specific target network device has been selected, many data base type operations may be performed, such as adding a new device, editing parameters on the device, activating a device, or deleting a particular device. The necessary parameters for the selected device may be provided either through keyboard data entry or through selection via a mouse.

To provide the user with further comprehension of the system, a plurality of hot link accesses from a particular network device to related information of the particular device, such as a detailed diagram or photograph of the device, may be provided. The detailed diagram or photograph may be supplemented by exploded diagrams of the device and how that device interconnects as well as a textual explanation of the purpose and capacity of each such device. Another feature provided by the display, is that a database query may be made of the system to show all network devices that possess certain qualities. For example, all devices that satisfy a particular query, such as all active devices on a particular base station 16 or connected to a particular CBSC 14, may appear in a designated color. This feature may be particularly useful in detecting defects in a network device such as a transceiver, before it fails completely. Another anticipated feature of the display device 50 and the system processor 40, is that requested additions or deletions made by the operator may be synthesized into a parts list such as an order form for new equipment. By using the display device 50 and operator commands to form a price list, rapid quotes may be made available to the customer. Although many display devices may be used, it is preferred that the device should be suited to three dimensional monitoring. An example of a suitable display device is a high speed graphics workstation, such as those made by Silicon Graphics, Inc.

Although FIG. 4 refers to the network devices of communication system 10 which is a cellular communication system, the present invention is applicable to many noncellular applications. For example, other communication network such as telephone networks, data networks or satellite networks may advantageously use the method and apparatus discussed above. In addition other systems such as utilities, transportation networks and assembly line or manufacturing environments could make use of displays such as those described herein.

The illustrative method and apparatus described herein have many advantages. For example, the apparatus provides the ability for a technical operator to quickly observe and monitor the status of any one of many components, such as transceivers and associated elements in a complex system. Consequently, the operator may more quickly detect and react to trouble spots in the system. In addition, system operators may more quickly gain familiarity with the system due to the three dimensional user friendly presentation of system components.

Further advantages and modifications of the above described apparatus and method will readily occur to those skilled in the art. The invention, in its broader aspects, is therefore not limited to the specific details, representative

apparatus, and illustrative examples shown and described above. Various modifications and variations can be made to the above specification without departing from the scope or spirit of the present invention, and it is intended that the present invention cover all such modifications and variations provided they come within the scope of the following claims and their equivalents.

What is claimed is:

1. A method of displaying hierarchical data comprising the steps of:

retrieving hierarchical network data representative of a status of a network, said data including a plurality of data elements, each data element associated with a network device; and

displaying the hierarchical network data onto a surface of a three dimensional structure, displayed on a two-dimensional display for the purpose of controlling the network based on the display.

2. The method of claim 1, wherein said structure comprises a conical object.

3. The method of claim 1, wherein said structure is selected from the group consisting essentially of spherical objects and concentric circular objects.

4. The method of claim 1, wherein said structure changes position over a period of time.

5. The method of claim 4, wherein said structure changes position in a tumbling pattern over said period of time.

6. The method of claim 1, wherein said surface has a plurality of display regions, at least some of said display regions representing at least some of the data elements.

7. The method of claim 6, wherein at least one of said plurality of display regions is uniquely selectable.

8. The method of claim 7, wherein further information is associated with the network device linked to the data ele-

ment represented by said at least one display region when said at least one display region is selected.

9. An apparatus for displaying hierarchical data comprising:

5 a display device;
a memory device storing the hierarchical data representative of a status of a network, said hierarchical data including a plurality of data elements, each data element associated with a network device; and
10 a processor responsive to said memory and including a graphical display module that displays the hierarchical network data onto a surface of a three dimensional structure, displayed on a two-dimensional display device, for the purpose of controlling the network based on the display.

15 10. The apparatus of claim 9, wherein said network device comprises a communication system network device.

11. The apparatus of claim 9, wherein said structure comprises one of a conical object and a spherical object.

12. The apparatus of claim 9, wherein said structure 20 position on the display device over a period of time.

13. The apparatus of claim 9, wherein said surface has a plurality of display regions, at least some of said display regions representing at least some of the data elements.

14. The apparatus of claim 13, further comprising a 25 pointing device in communication with said display device, and wherein at least one of said plurality of display regions is uniquely selectable by said pointing device.

15. The apparatus of claims 9, wherein said memory device comprises a first memory area storing status data associated with each network device and a second memory area storing network device relationship data defining a relationship between the data elements.

* * * * *



US006504535B1

(12) **United States Patent**
Edmark

(10) Patent No.: **US 6,504,535 B1**
(45) Date of Patent: **Jan. 7, 2003**

(54) **DISPLAY TECHNIQUES FOR THREE-DIMENSIONAL VIRTUAL REALITY**

(75) Inventor: **John T. Edmark, New York, NY (US)**

(73) Assignee: **Lucent Technologies Inc., Murray Hill, NJ (US)**

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/191,012**

(22) Filed: **Nov. 12, 1998**

Related U.S. Application Data

(63) Continuation-in-part of application No. 09/160,758, filed on Sep. 25, 1998, which is a continuation-in-part of application No. 09/107,059, filed on Jun. 30, 1998.

(51) **Int. Cl.**⁷ **G06T 15/00**

(52) **U.S. Cl.** **345/419; 345/427; 345/428; 345/629; 345/632**

(58) **Field of Search** **345/132, 427, 345/428, 419, 423, 426, 473, 629, 632, 634, 638, 639, 640, 641, 646, 647**

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Primary Examiner—Mark Zimmerman

Assistant Examiner—Enrique L Santiago

(74) **Attorney, Agent, or Firm**—John G. De La Rosa

(57) **ABSTRACT**

A limitation of using two-dimensional images, such as videos or photographs, to represent portions of a three-dimensional world occurs when the user moves within the world and views the world from a location different than from the original context of the two-dimensional image, i.e., from a location different than the image's ideal viewing point (IVP). View changes result in the image not aligning well with the surrounding objects of the three-dimensional world. This limitation is overcome by distorting the two-dimensional image so as to adjust the image's vanishing point(s) in accordance with the movement of the user using a pyramidal panel structure. In this manner, as the user moves away from the ideal viewing point, the distortions act to limit the discontinuities between the two-dimensional image and its surroundings. To minimize the depth profile of the pyramidal panel structure, the structure may be segmented into sections and each section translated towards, or away from, the user's viewpoint. Also, a hierarchical image resolution may be used, with portions of the image near the center or vanishing point having a higher resolution than the portions of the image near its perimeter.

15 Claims, 14 Drawing Sheets

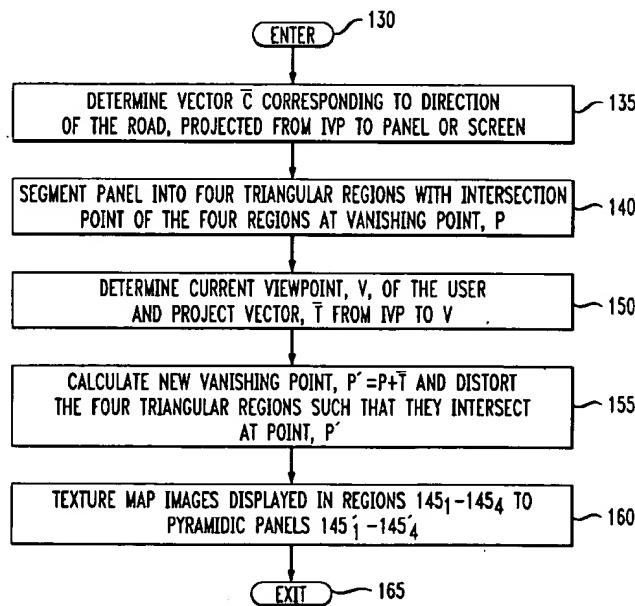


FIG. 1

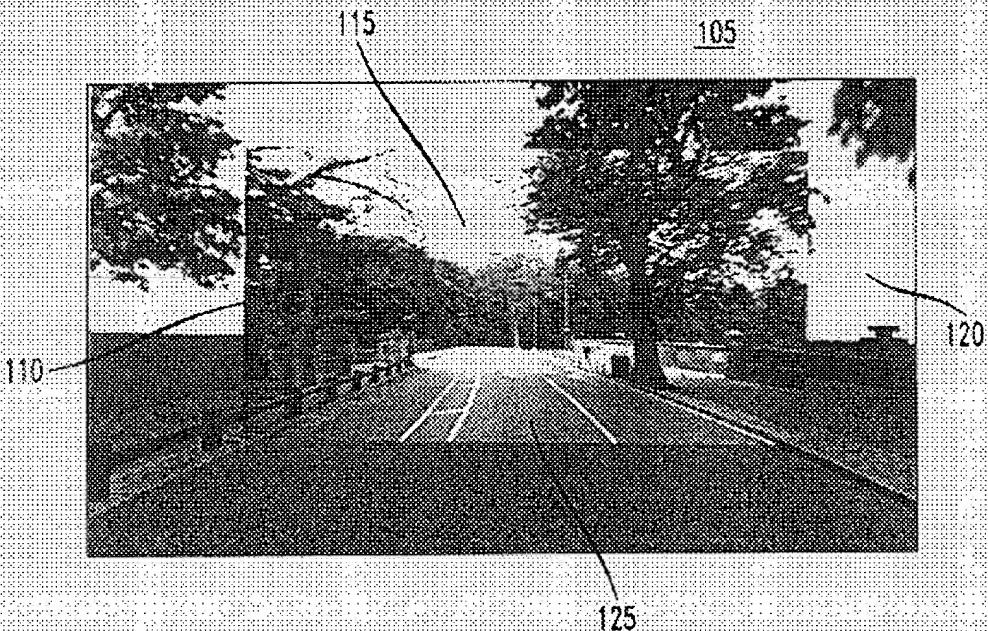


FIG. 2

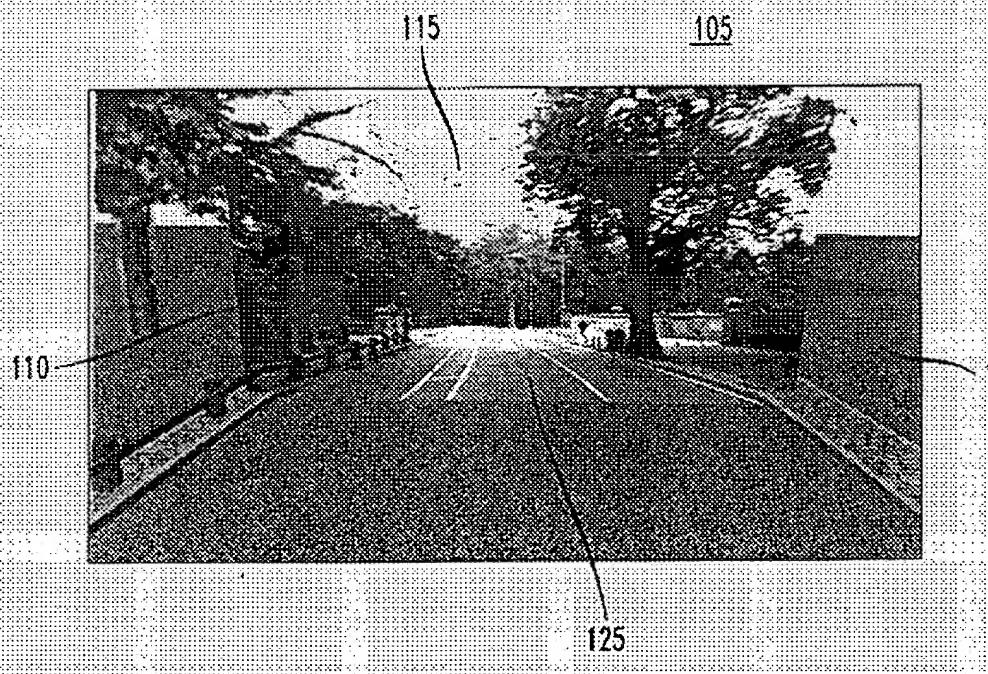


FIG. 3

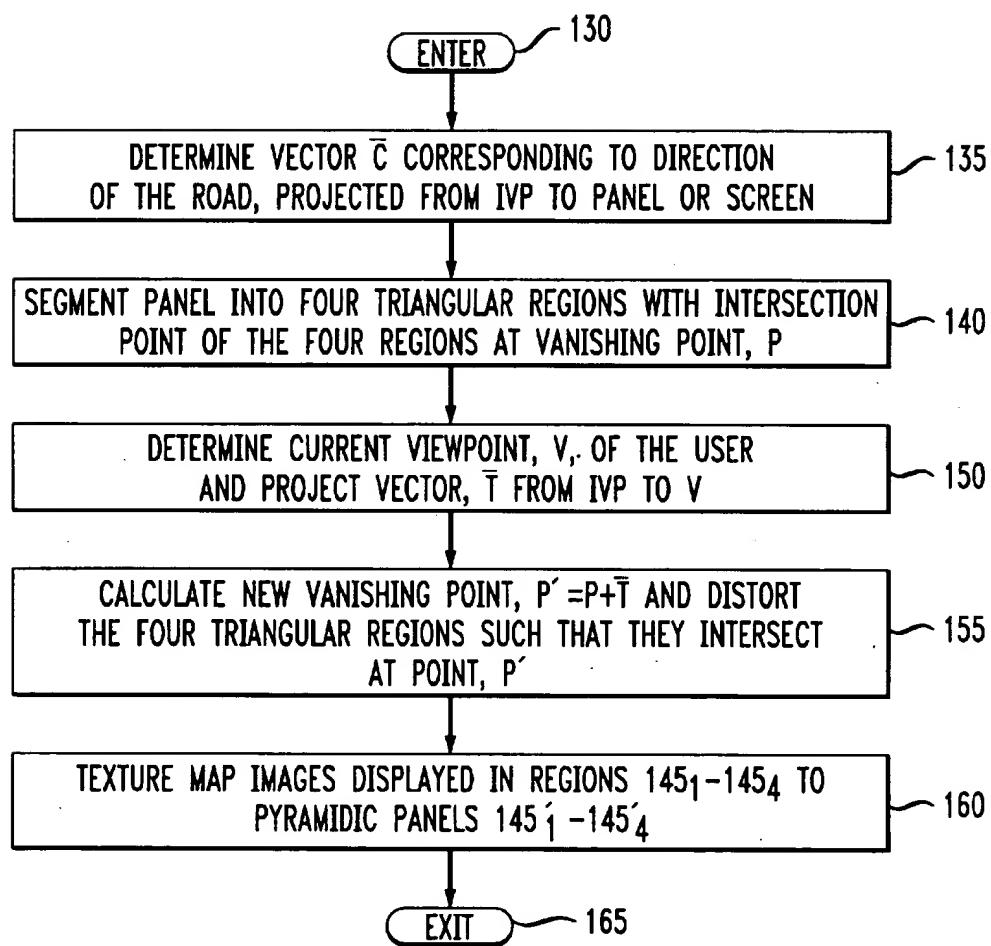


FIG. 4

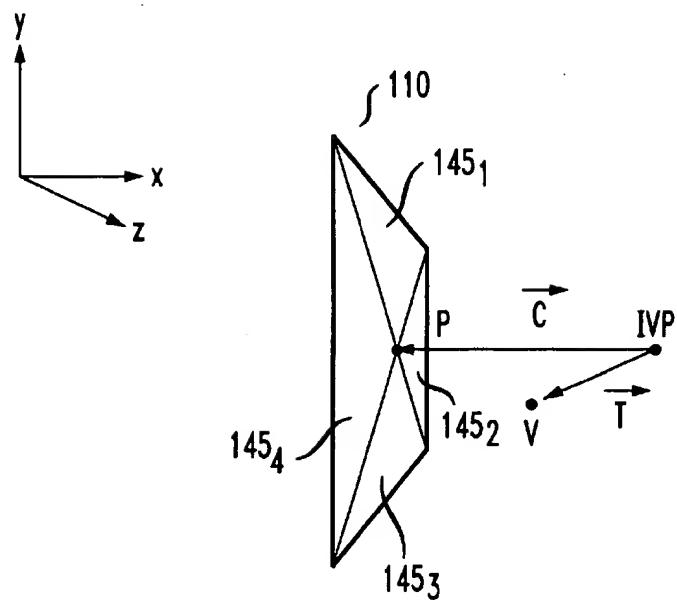


FIG. 5

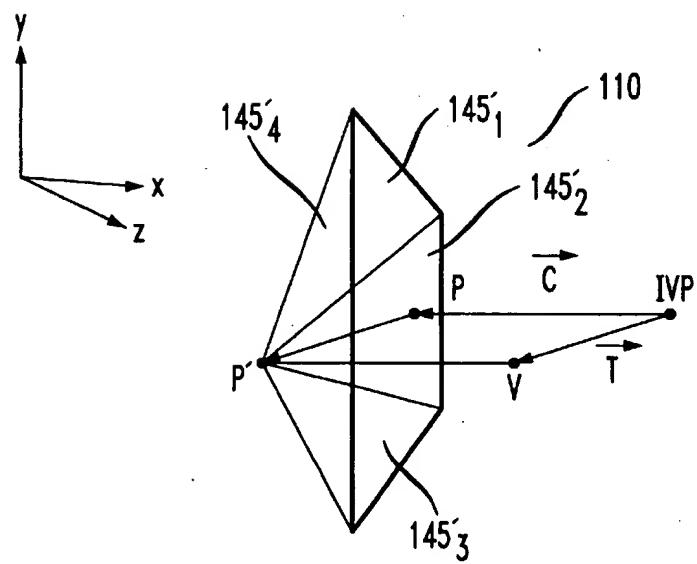


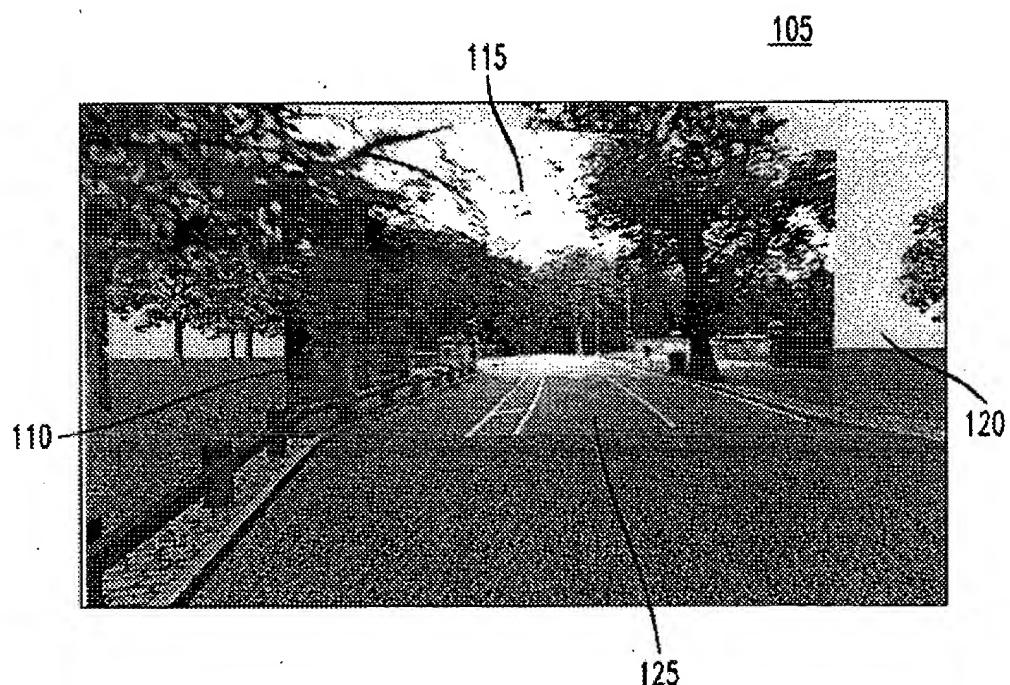
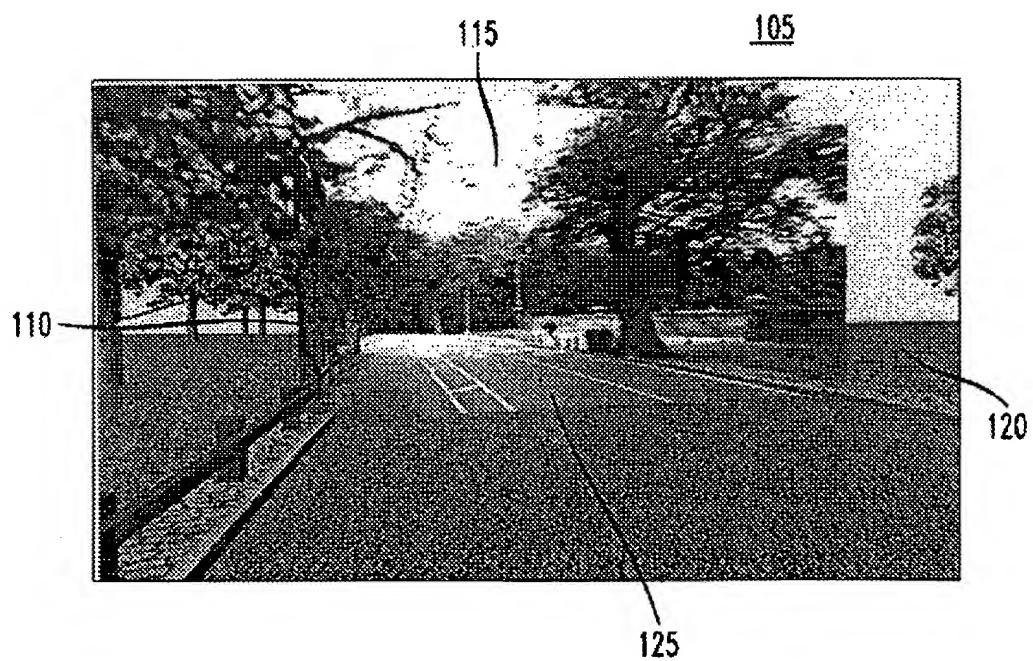
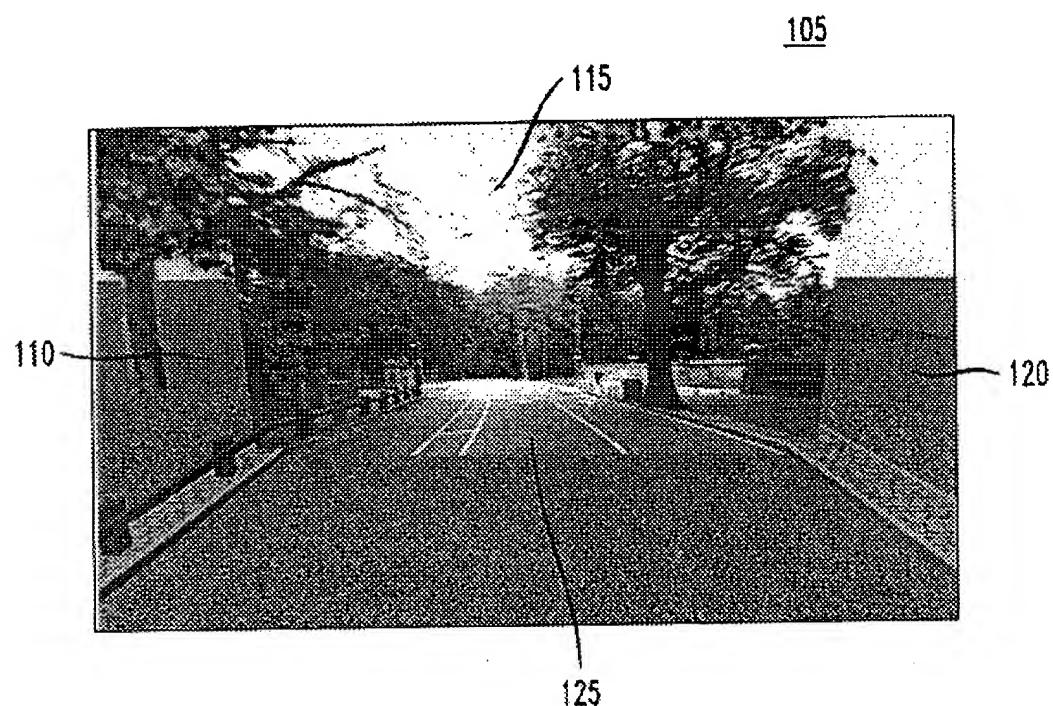
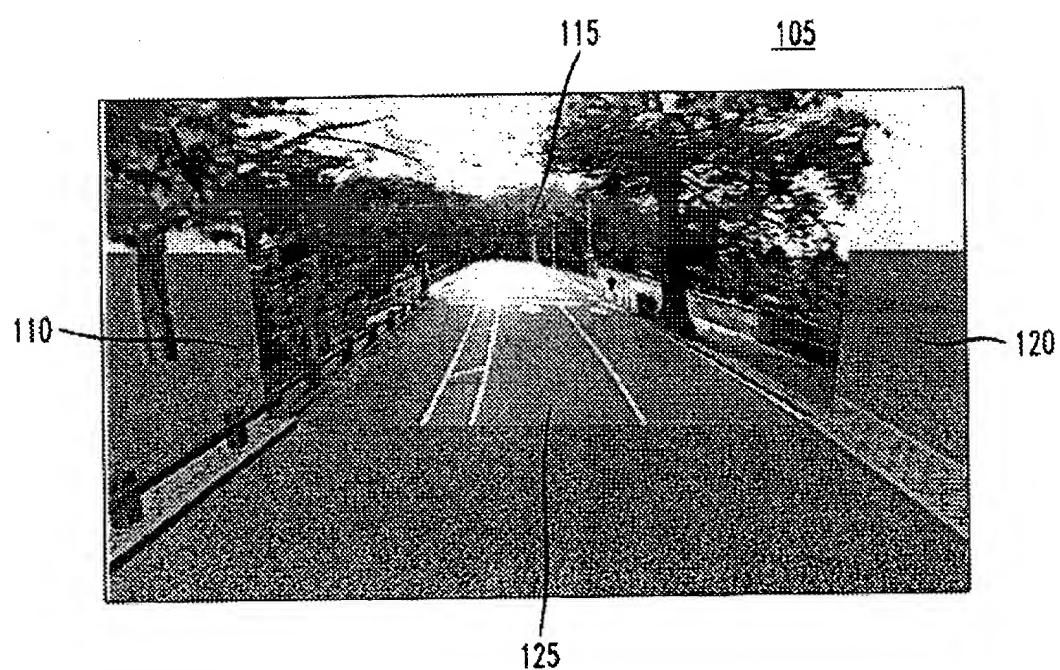
FIG. 6A*FIG. 6B*

FIG. 7A*FIG. 7B*

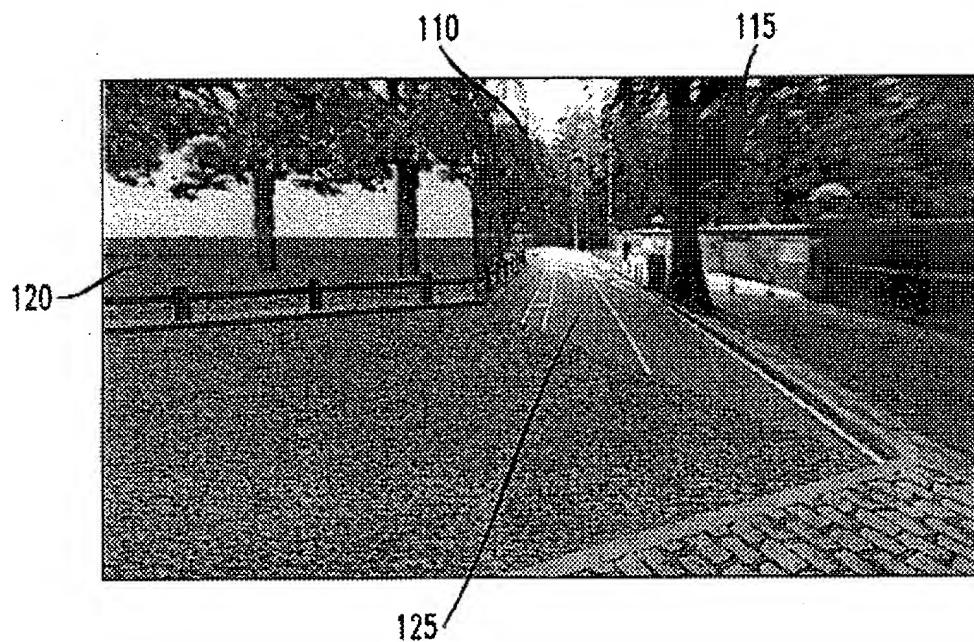
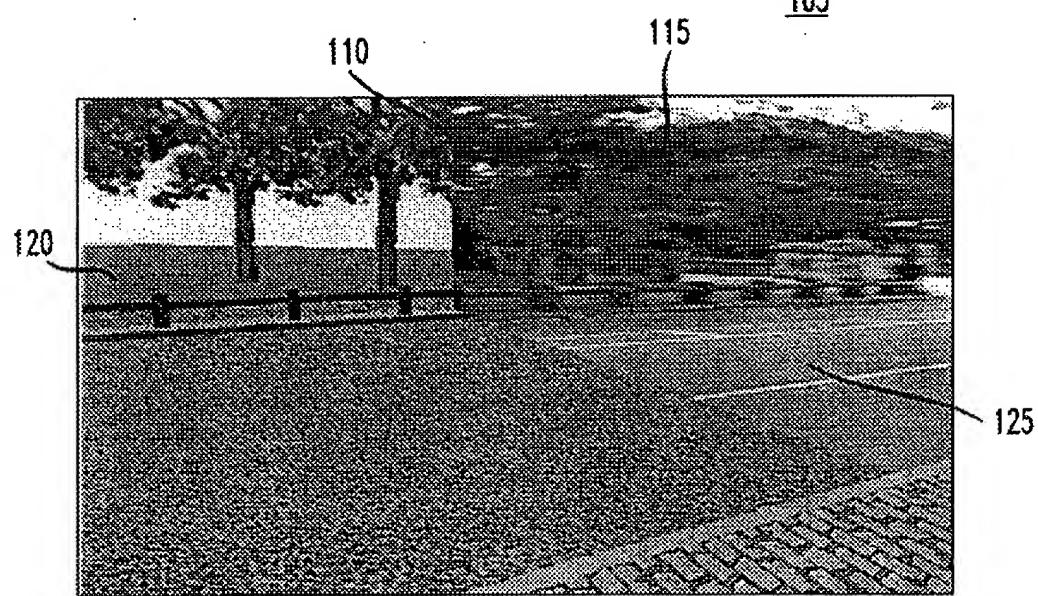
*FIG. 8A*105*FIG. 8B*105

FIG. 9

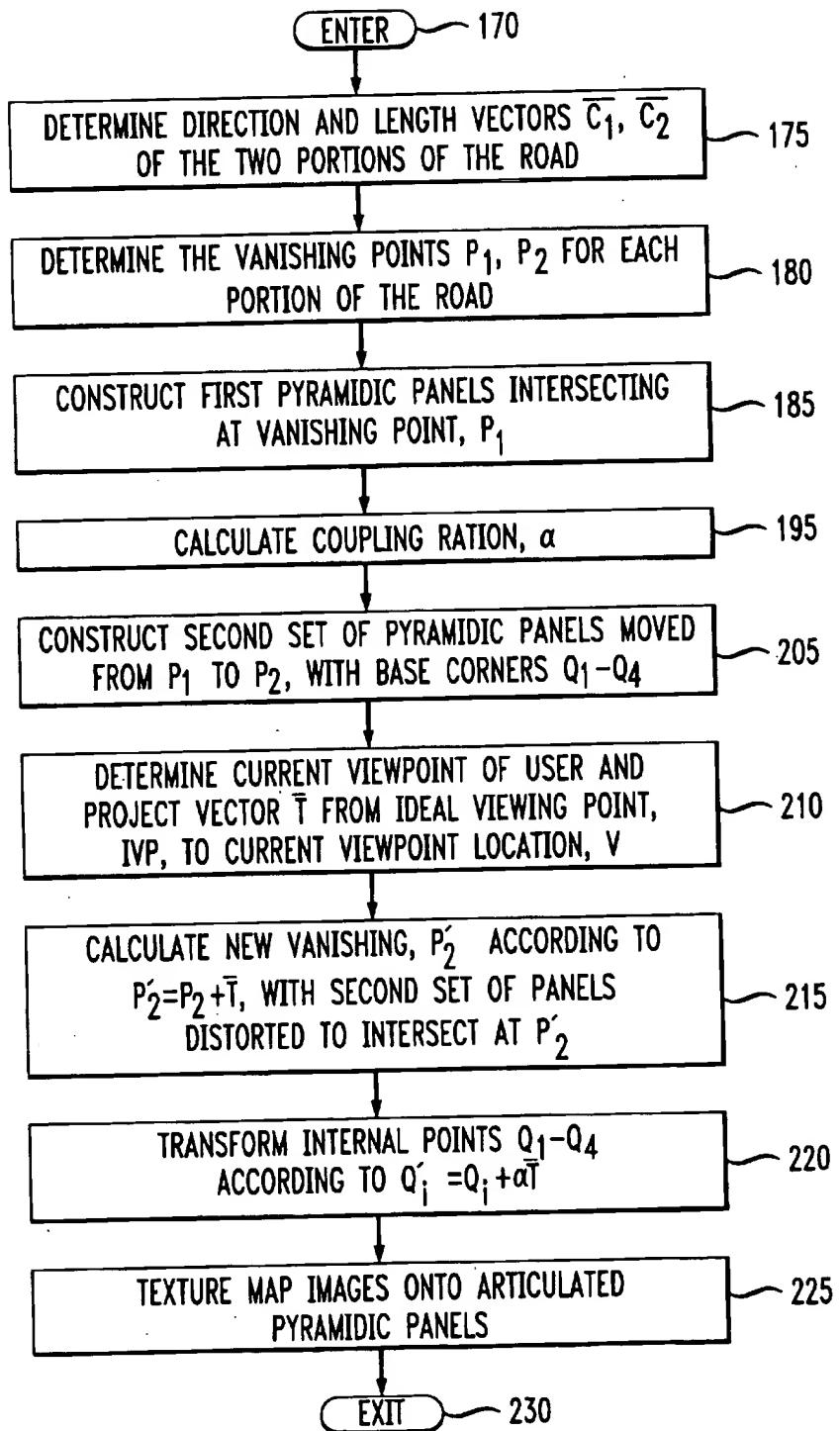


FIG. 10

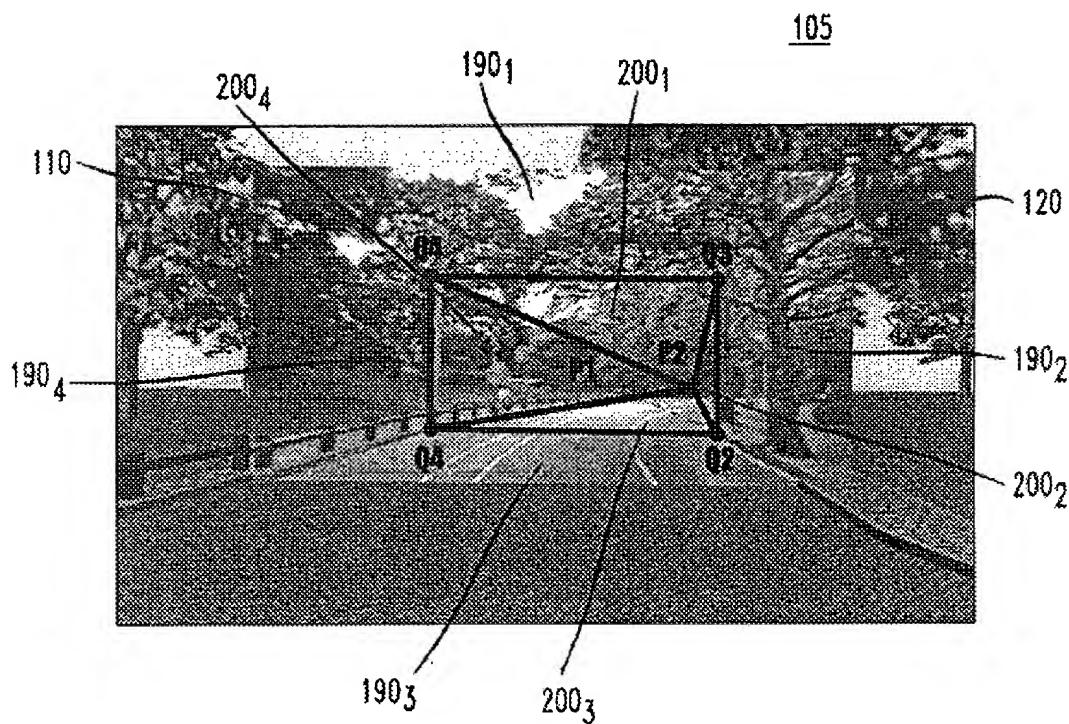


FIG. 11

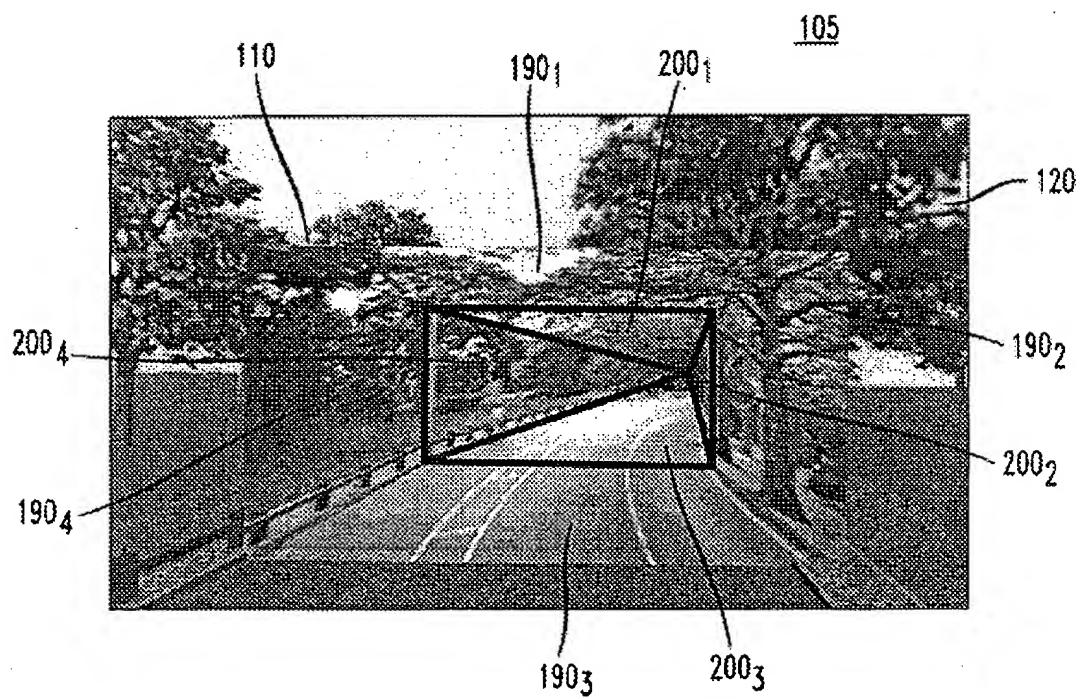


FIG. 12

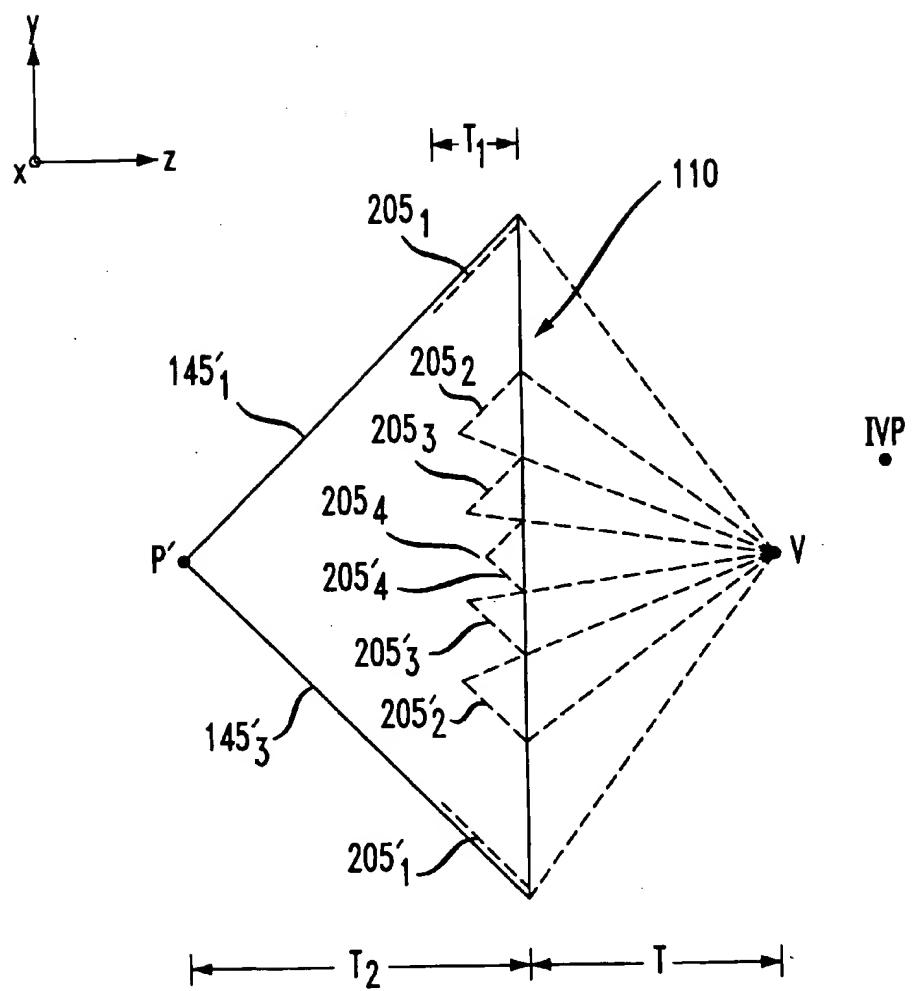


FIG. 13

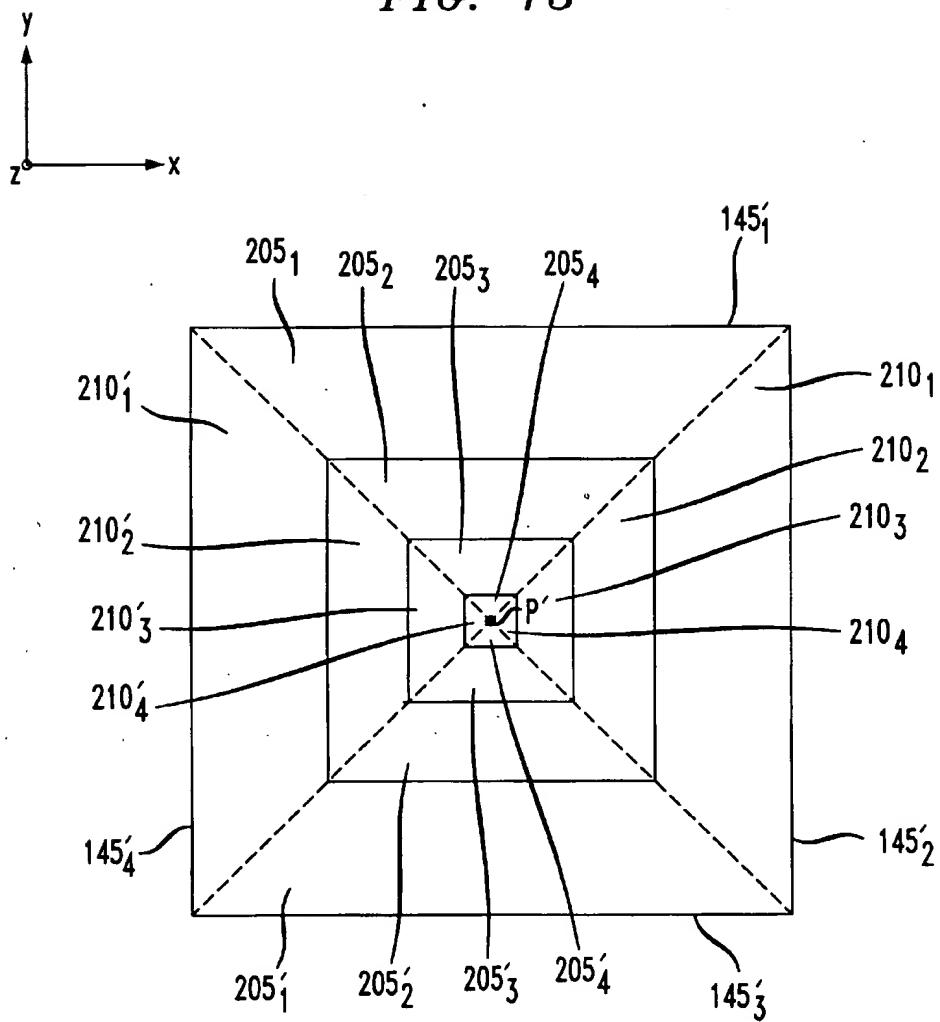
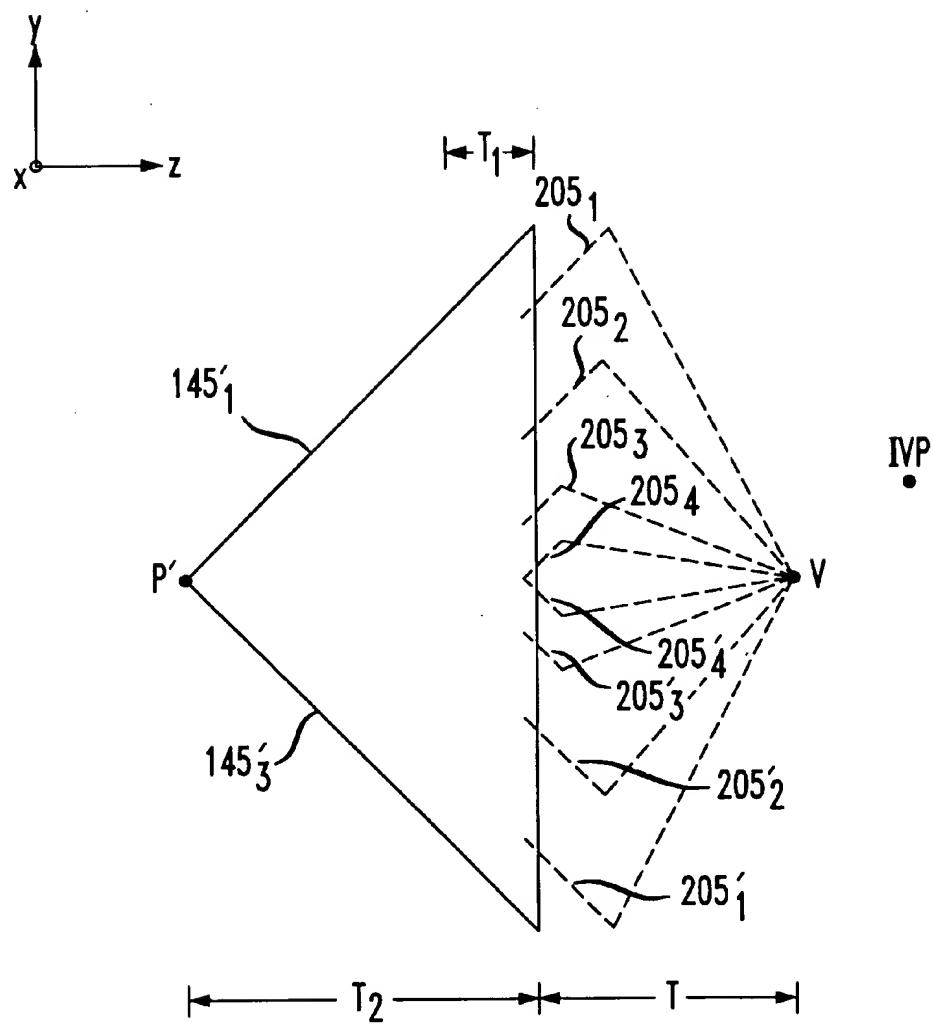


FIG. 14



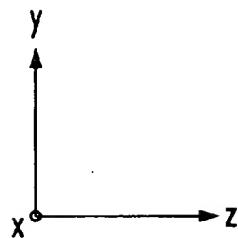
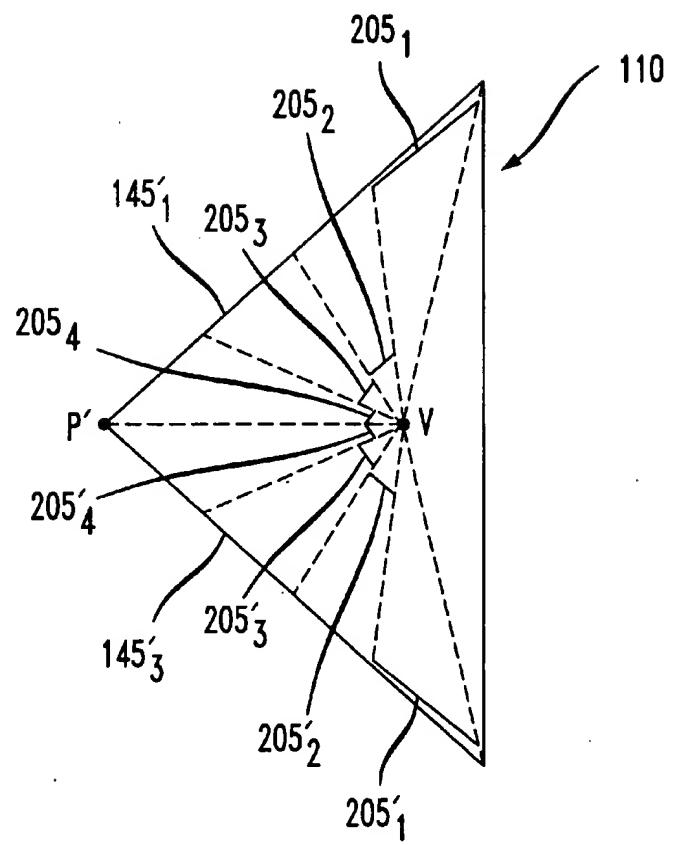


FIG. 15



• IVP

FIG. 16

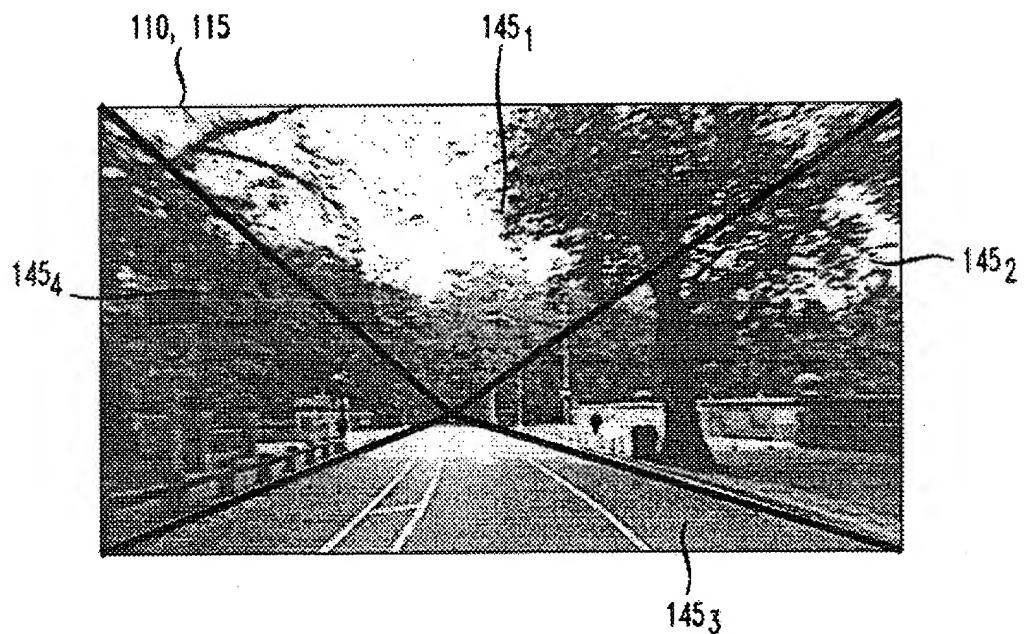


FIG. 17

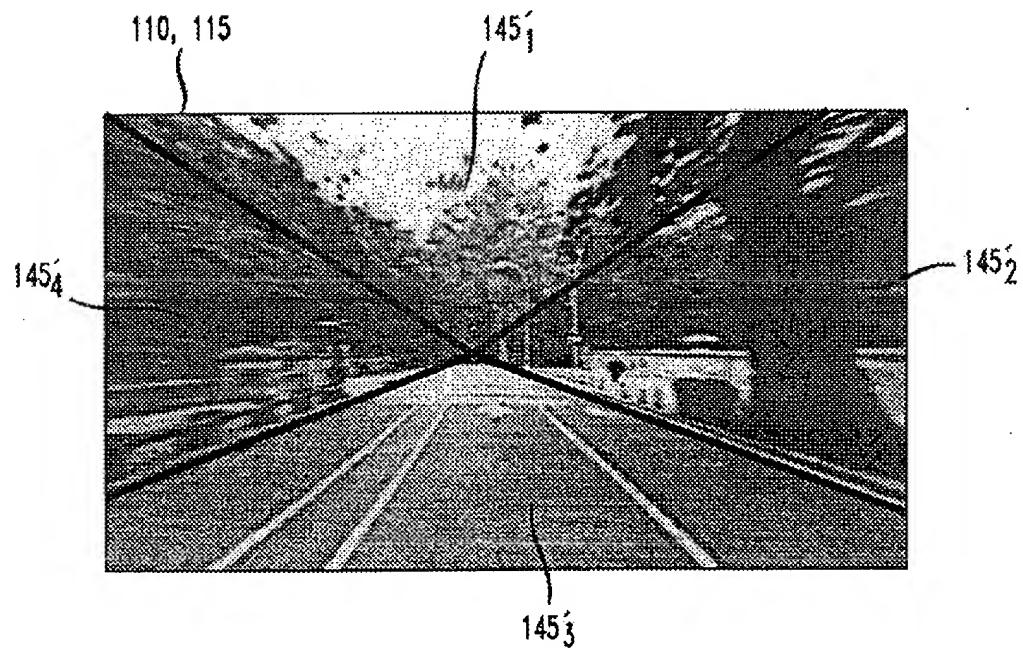
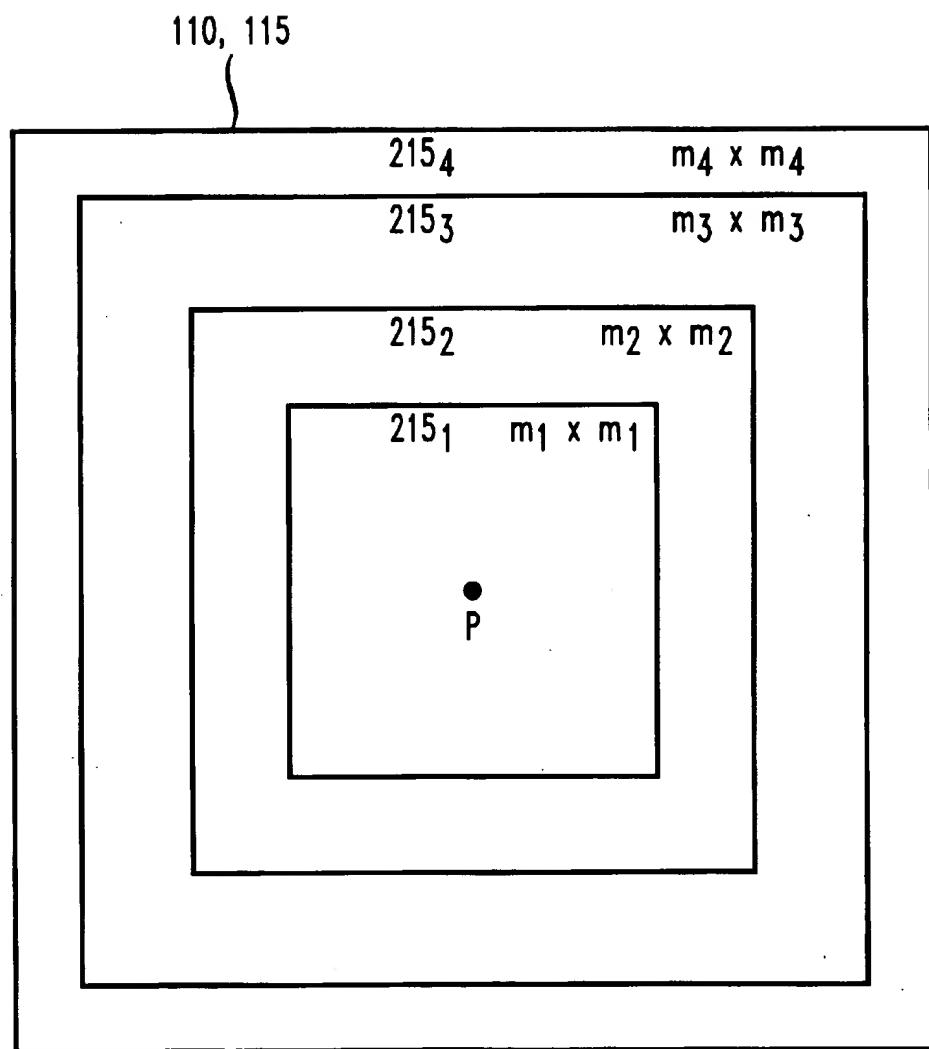


FIG. 18



DISPLAY TECHNIQUES FOR THREE-DIMENSIONAL VIRTUAL REALITY

CROSS-REFERENCE TO RELATED APPLICATION

This application is related to co-pending U.S. patent application Ser. No. 09/190,743 filed concurrently herewith (Case Edmark-7). Also, this application is a continuation-in-part of U.S. patent application Ser. No. 09/160,758 filed Sep. 25, 1998 (Case Edmark-5), which is a continuation-in-part of U.S. patent application Ser. No. 09/107,059 filed Jun. 30, 1998 (Case Edmark-2). The above-identified co-pending applications, which are commonly assigned, are incorporated herein by reference.

TECHNICAL FIELD

This invention relates to the integration of three-dimensional computer graphics and a two-dimensional image to provide a realistic three-dimensional virtual reality experience.

BACKGROUND OF THE INVENTION

The display of a three-dimensional virtual reality world to a user requires considerable computation power, and it is typically costly to develop the necessary highly detailed models required for doing so. In order to simplify the problem, two-dimensional images, such as videos or photographs, may be used to represent or simulate portions of the three-dimensional world. A great reduction in computation power and cost can be achieved by such an arrangement.

SUMMARY OF THE INVENTION

A limitation of such a world occurs when a user moves within the world and views the world from a location different than the original context of a two-dimensional image which has been carefully calibrated to "fit into" the world. View changes, such as from a location different than the image's ideal viewing point, result in the image not aligning or fitting well with the surrounding objects of the three-dimensional world. I have recognized that, in accordance with the principles of the invention, viewpoint changes may be dealt with by distorting the two-dimensional image so as to adjust the image's vanishing point(s) in accordance with the movement of the user using a novel "pyramidal panel structure." In this manner, as the user moves away from the ideal viewing point, the distortions act to limit the discontinuities between the two-dimensional image and the surroundings of the world.

In another aspect of the present invention, the pyramidal panel structure may be segmented into sections, each translated towards or away from the user's viewpoint and then scaled, so as to minimize the depth profile of the pyramidal panel structure. In yet still another aspect of the present invention, a hierarchical image resolution may be used, with portions of the image near the center of the image having a higher resolution than the portions of the image near its perimeter.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings:

FIG. 1 shows an example of that which a user sees when a user views the world from the ideal viewing point for a two-dimensional image representing a portion of the world;

FIG. 2 shows an example of that which a user sees when a user moves within the world of FIG. 1 and views the two-dimensional image from a location different than the image's ideal viewing point, without the use of the present invention;

FIG. 3 shows an exemplary process, in accordance with the principles of the invention, for distorting the two-dimensional image using a pyramidal panel structure so as to adjust the image's vanishing point in accordance with the movement of the user;

FIGS. 4 and 5 depict the pyramidal panel structure of the present invention for distorting the two-dimensional image so as to adjust the image's vanishing point, in accordance with the movement of the user;

FIGS. 6A-B depict examples of that which a user sees when a user views the world from a location left of the image's ideal viewing point, without and with the use of the present invention, respectively;

FIGS. 7A-B depict examples of that which a user sees when a user views the world from a location above the image's ideal viewing point, without and with the use of the present invention, respectively;

FIGS. 8A-B depict examples of that which a user sees when a user views the world from a location toward the front and the right of the image's ideal viewing point, without and with the use of the present invention, respectively;

FIG. 9 shows an exemplary process, in accordance with the principles of the invention, for distorting a two-dimensional image using an articulated pyramidal panel structure so as to adjust multiple vanishing points in the image, in accordance with the movement of the user;

FIG. 10 depicts an example of the articulated pyramidal panel structure of the present invention;

FIG. 11 depicts an example of that which a user sees when a user views the world from a location away from the ideal viewing point of the two-dimensional image, with the use of the articulated pyramidal panel structure of the present invention;

FIGS. 12 and 13 depict side and front views, respectively, of the pyramidal panel structure of FIG. 5 with each panel segmented into a plurality of sections;

FIG. 14 depicts the pyramidal panel structure of FIG. 5, with each panel segmented into a plurality of sections having its centers located on the surface of a predetermined plane;

FIG. 15 depicts the pyramidal panel structure of FIG. 5, with each panel segmented into a plurality of sections and each section translated a different distance toward the user's view point, V;

FIG. 16 depicts the screen of the pyramidal panel structure of the present invention segmented into four triangular sections with the corresponding portions of a two-dimensional image displayed in each panel;

FIG. 17 depicts the screen of FIG. 16 from a location closer to the center of the image, with the corresponding portions of the image textured-mapped onto the pyramidal panels in accordance with the present invention; and

FIG. 18 depicts the screen of FIG. 16 with the two-dimensional image segmented into a plurality of sections in accordance with another aspect of the present invention.

DETAILED DESCRIPTION

To better understand the invention, FIGS. 1-2 show examples of that which user sees when the user moves

within a three-dimensional virtual reality world (x,y,z) and views a two-dimensional image (x,y) representing a portion of the world from a location at the image's ideal viewing point (IVP), and then from a different location, i.e., a location different than the original context of the image. It should be understood that the two-dimensional image has been carefully calibrated to "fit into" the surroundings of the world. For simplification of terminology purposes, we shall use the term two-dimensional image to denote either a video clip or a photograph. In accordance with the principles of the invention, as the user moves away from the ideal viewing point, discontinuities between the two-dimensional image and its surroundings are minimized by distorting the image according to the movement of the user.

FIG. 1 shows an exemplary three-dimensional reality world 105, which is a bicycle path in a park, e.g., Central Park in New York City. In representing world 105, the present invention exploits a characteristic common for images consisting of views looking down the center of roads, streets or paths, which is that they may be treated as perspective, corridor-like images, with features closer to the center of the image being farther away from the viewer along the z-axis. Accordingly, the bicycle path or road and its immediate vicinity are treated as a kind of three-dimensional, corridor-like image whose floor is formed by the roadbed; whose ceiling is formed by the sky, and whose sidewalls are formed by the roadside objects. In this manner, the principles of a simple point perspective can be used for distorting the landscape image in accordance with the movement of the viewer, as discussed herein below.

World 105 is divided into two portions, screen or panel 110 on which is shown or displayed a two-dimensional image 115, such as a still photograph, picture, or a current frame of a video clip; and the remainder of the world 120, which is represented using computer graphics techniques, and is thus referred to herein as computer graphics (CG) Part 120. Within CG Part 120 there are various synthetic, three-dimensional landscapes or objects modeled in, for example, the Virtual Reality Modeling Language (VRML). Two-dimensional image 115 simulates landscape or terrain portions of the world 105, here a virtual road or course 125 for walking, running or pedaling a bicycle.

Note that although three-dimensional world 105 cannot be actually rendered in a two-dimensional plane (x,y), it can be projected to and displayed on a two-dimensional plane so as to appear to have three dimensions (x,y,z). Accordingly, the techniques of the present invention are preferably employed with computers and software, which are sufficiently sophisticated to display images on a two-dimensional plane as having three dimensions. Note also that to make the world look realistic, computer graphics display techniques use the z component of objects to scale accordingly the x and y components as a function of its distance (z-axis) to the user's viewpoint.

Two-dimensional image 115 is carefully placed, cropped and sized to achieve continuity with the surrounding environment of the CG Part 120. Note that the image is clipped so that the left and right edges of the road in CG Part 120 pass through the left and right bottom corners of the road, respectively, in image 115. This clipping ensures that the roadbed maps to the floor of the hypothetical corridor. In so doing, portions at the boundary between two-dimensional image 115 and CG part 120 are co-planar, i.e., at the same distance away along the z-axis from the user's viewpoint. In "fitting" two-dimensional image 115 to CG part 120, however, there exists only one viewpoint from which that image's content properly corresponds to the surrounding

environment of CG Part 120. This unique location is called the image's ideal viewing point (IVP). In FIG. 1, two-dimensional image 115 is seen from its ideal viewing point, and from this view, image 115 aligns well with the surrounding objects of CG Part 120.

Users, however, rarely view image 115 only from its ideal viewing point. As the user moves within world 105, such as left or right of road 125, as they round curves, or move closer to or farther from the image, they see image 115 from positions other than its ideal viewing point. Absent the use of the present invention, such viewpoint changes would cause objects or features within image 115 to align improperly with the surrounding environment, as further illustrated in FIG. 2.

In accordance with the principles of the invention, however, screen or panel 110 uses a display structure called a "pyramidal panel structure" for displaying two-dimensional image 115 within the surrounding three-dimensional space of the CG Part 105 so as to deal with viewpoint changes. The transformations associated with the pyramidal panel structure dynamically distort two-dimensional image 115 according to viewer's position so as to adjust the image's vanishing point with the viewer's movement. As the viewer moves from the image's ideal viewing point, these distortions act to limit discontinuities between image 115 and the surroundings of CG Part 120.

FIG. 3 shows an exemplary process in accordance with the principles of the invention for distorting two-dimensional image 115 so as to adjust its vanishing point in accordance with the viewer's position. The process is entered at step 130 whenever it is determined that the viewer's position has changed.

Using the virtual world's road model of the CG Part 105, a vector, \vec{C} , corresponding to the direction of road 125 is projected at step 135 from the image's ideal viewing point, IVP, to panel or screen 110 on which is displayed image 115. Note that the panel is two-dimensional, but represents three-dimensional space with objects nearer the center of the image being farther away from the plane of the viewer. The panel structure is shown in FIG. 4. The point of intersection with screen or panel 110 is the image's vanishing point, P . Note, however, that the vanishing point may be set visually by the user, if desired, or by other suitable computer graphics processing techniques known in the art. Next, in step 140, screen or panel 110 is segmented into four triangular regions 145₁₋₄, one for each of the regions bordering CG Part 120, with the intersection point of the four regions located at the vanishing point, P .

Thereafter in step 150, the current viewpoint of the user, V , is determined, and a vector \vec{T} projected from the ideal viewing point, IVP, to the viewer's current location, V . In accordance with the principles of the invention, as the viewer moves, a new vanishing point P' is calculated as $P' = P + \vec{T}$. The four triangular regions 145₁₋₄ are distorted in the three-dimensional space of the virtual world at step 155 to represent the mapping of objects nearer the center of the image being displaced farther away from the viewpoint of the user. The four triangular regions intersect at the new vanishing point P' and form so-called "pyramidal panels" 145'₁₋₄. This is illustrated in FIG. 5. At step 160, the corresponding images displayed in regions 145₁₋₄ are then "texture-mapped" onto pyramidal panels 145'₁₋₄, respectively. In this manner, as the viewer moves away from the image's ideal viewing point, IVP, distortions in the image resulting from moving the image's vanishing point from P to P' act to limit the discontinuities between image 115 and the surroundings within CG Part 105.

In the exemplary illustration of FIG. 5, distorting image 115 so as to move the vanishing point from P to P' results in pyramidal panel structure forming a four-sided pyramid. Note that its base is fixed and corresponds to original screen or panel 110, with its peak located at P', which moves in concert with the viewer's current location, V. As the user's viewpoint moves closer to and farther from the image, the image's vanishing point accordingly moves farther from and closer to the user's viewpoint, respectively.

FIGS. 6 through 8 compare the display of two-dimensional image 115 on screen or panel 110 with the display of the same image using the "pyramidal" panels of the present invention. More specifically, FIGS. 6A, 7A and 8A depict viewing two-dimensional image 115 at a location from the left, above, and in front and to the right of the image's ideal viewing point, IVP, respectively, without the use of the present invention. In these latter figures, note that there are discontinuities between the edges of the road and the three-dimensional space of CG Part 105. FIGS. 6B, 7B and 8C depict the same two-dimensional image distorted and texture-mapped onto pyramidal panels 145₁₋₄, in accordance with the principles of the invention. Note that in these latter figures, the discontinuities in the road edge have been substantially eliminated.

In another embodiment of the present invention, a modified pyramidal panel structure may be used to deal with two-dimensional images containing curved roads, streets, paths and other corridor-like images containing multiple rather than a single vanishing point. In this latter case, screen or panel 110 is segmented using multiple vanishing points to form a so called "articulated pyramidal panel structure." The transformations associated with the articulated pyramidal panel structure dynamically distort different portions of two-dimensional image 115 according to viewer positions so as to adjust the different vanishing points of the image with the viewer's movement. Likewise, as the viewer moves from the image's ideal viewing point, these distortions act to limit the discontinuities between two-dimensional image 115 and the surroundings of CG Part 120.

FIG. 9 shows an exemplary process in accordance with the principles of the invention for distorting two-dimensional image 115 using an articulated pyramidal panel structure. Again, the process is entered at step 170 whenever it is determined that the viewer's position has changed. In general, curve road 125 is treated as two straight corridors placed end-to-end, extending back from screen or panel 110. Each corridor represents a different portion of road 125 in the three-dimensional space of world 105, with features nearer the center of the image being farther away from the user's viewpoint.

Using the virtual world's road model of the CG Part 105, corresponding directional vectors C₁ and C₂ of the corridors are determined at step 175. Note that portion of the road nearer to the user's viewpoint is represented by C₁, and the portion farther away is represented by C₂. Next, in step 180, using the vectors C₁ and C₂, the corresponding vanishing points P₁ and P₂ are determined, respectively, for each corridor by projecting those vectors from the image's ideal viewing point, IVP. Alternatively, vanishing points P₁ and P₂ may be determined visually by the user, or by some other suitable means known in the art. In step 185, using the first corridor's vanishing point, P₁, a first set of pyramidal panels 190₁₋₄ are constructed to intersect at vanishing point, P₁, as shown in FIG. 10.

Now at step 195, a coupling ratio α is calculated according to the following equation: $\alpha = l/(l+d)$, where l is the length

of the first corridor, and d is the distance between the image's ideal view point (IVP) and the base of pyramidal panels 190₁₋₄. Each line segment connecting a corner of the base to vanishing point P₁ is then divided into two segments by a point placed according to the coupling ratio, α . More specifically, the length l' of each line segment from the corner of the base of panels 190₁₋₄ to this point is given by $l' = \alpha l$, where l' is the total length of the segment between the corner of the panel and the vanishing point, P₁. These four points labeled Q1 through Q4 are connected to form the base of a second set of smaller pyramidal panels 200₁₋₄ embedded within the larger panels (step 205), as further illustrated in FIG. 10. The intersection point of pyramidal panels 200₁₋₄ is then moved from P₁ to vanishing point, P₂.

For the articulated pyramidal panel structure, the current viewpoint of the user, V, is determined, and a vector T projected from the ideal viewing point, IVP, to the viewer's current location, V (step 210). As the viewer moves, a new vanishing point P₂' is calculated as $P_2' = P_2 + T$ at step 215, and panels 200₁₋₄ are then distorted so as to intersect at P₂'. As the viewer moves, the four internal points Q1 through Q4 are mapped with the viewer's movement to Q1' through Q4', respectively, in accordance with the following relationship: $Q_i' = Q_i + \alpha T$, at step 220. Note that doing so, accordingly distorts the first set of pyramidal panels 190₁₋₄. At step 225, the corresponding images in original panels are then texture-mapped into articulated pyramidal panels 190₁₋₄ and 200₁₋₄, which have been distorted in accordance with the movement of the viewer. Note that to unambiguously texture-map onto panels 190₁₋₄, these panels are each subdivided into two triangular subregions and then texture-mapped. Shown in FIG. 11 is image 115 seen from a location away from the image's ideal viewing point, using the articulated pyramidal panel structure of the present invention.

Note that the above articulated pyramidal panel structure may also use more than two sets of pyramidal panel structures. Instead of treating the curve road as two straight corridors, multiple corridors may be employed, each placed end-to-end and extending back from screen or panel 110. Likewise, each corridor represents a different portion of road 125 in the three-dimensional space of world 105, with features nearer the center of the image being farther away from the user's viewpoint. In such a case, each set of articulated pyramidal panels are formed reiterately using the above described procedure.

Referring to FIGS. 12-13, there is shown a third embodiment of the present invention which is similar to that of FIG. 5 and in which "pyramidal panels" 145₁, 145₂, 145₃ and 145₄ have been now multi-segmented into sections 205₁₋₄, 210₁₋₄, 205₁₋₄, and 210₁₋₄, respectively, with the images in original panels 145₁₋₄ then texture-mapped into the corresponding translated sections of the pyramidal panel structure, as discussed herein below. It should be recalled that the pyramidal panel structure represents the three-dimensional mapping (x,y,z) of two-dimensional image 115 onto image screen or panel 110 (x,y). Advantageously, the embodiment of FIGS. 12-13 minimizes the depth profile of the pyramidal panel structure along the z-axis. Unlike the embodiment of FIG. 5, the depth profile of this third embodiment does not substantially vary with changes in the user's viewpoint, V. In the exemplary embodiment of FIG. 5, recall that distorting image 115 so as to move the vanishing point from P to P' results in the pyramidal panel structure forming a four-sided pyramid. The base of the pyramid is fixed and corresponds to original screen or panel 110, with its peak located at P' and moves in concert with the viewer's current location, V. As the user's viewpoint moves

along the z-axis closer to and farther from two-dimensional image 115, the image's new vanishing point P' moves farther from and closer to the user's viewpoint, respectively. This latter movement causes the depth profile along the z-axis of the pyramidal panel structure to vary accordingly. Unfortunately, this variation in depth profile can undesirably and/or unexpectedly occlude from the user's view objects in the virtual world, or cause objects to occlude other features in the virtual world inasmuch as the corresponding images in the panels are distorted, as discussed above herein.

To obviate the aforementioned problem, "pyramidal panels" 145₁₋₄', 145₂', 145₃' and 145₄' have been multi-segmented into sections 205₁₋₄, 210₁₋₄, 205₁₋₄', and 210₁₋₄' respectively. Each section is then translated along the z-axis to a predetermined distance towards or away from the user's viewpoint, V, but importantly of the same orientation as the original section. For example, segmented sections 205₁₋₄ and 205₁₋₄' may each have one of its outer edge along the x-axis translated to lie on the x,y plane of screen or panel 110, as shown in phantom in FIG. 12. As the user moves to a new viewpoint, each section in effect pivots about that edge along the x-axis, which edge lies on the surface of panel 110. Similarly, section 210₁₋₄ and 210₁₋₄' may each have one of its outer edge along the y-axis lying on the surface of panel 110. Alternatively, sections 205₁₋₄, and 205₁₋₄' may be centered along panel 110, as depicted in FIG. 14. Likewise, sections 210₁₋₄ and 210₁₋₄' may be similarly translated, but for the sake of clarity are not shown in FIGS. 12 and 14.

Still further, each of sections 205₁₋₄ and 205₁₋₄' may in effect be rotated or pivoted about its other edge along the x-axis as the user moves to a new viewpoint, V, or, in general, about an axis parallel with an edge along the x-axis of the corresponding section. Again, this latter axis may, but does not have to, lie on the surface of panel 110. Regardless of the segmenting method chosen, however, translating each section towards or away from the user's viewpoint significantly reduces the depth profile of the pyramidal panel structure along the z-axis, such as depicted in FIG. 12 from, for example, T₂ to T₁.

In still another embodiment of the present invention, sections 205₁₋₄ and 205₁₋₄' may each be translated a different distance along the z-axis, as illustrated in FIG. 15. Although not shown, sections 210₁₋₄ and 210₁₋₄' may likewise be translated. Those skilled in the art will readily understand that doing so advantageously allows the user's viewpoint, V, to extend in front of panel 110 inasmuch as segmented sections corresponding to the image's center may be offset and located closer to the user's viewpoint, V, than the outer sections.

Also, note that segmenting the pyramidal panel structure into a greater number of smaller sections accordingly only further reduces the depth profile, which asymptotically approaches a zero thickness. It is contemplated that the number of sections that the panel structure is divided into may be chosen empirically based on image content as well as the user's range of movement within the virtual world. Preferably, however, the panel structure is dynamically segmented in a reiterative manner. For example, once a user has chosen the maximum desired depth for the panel structure along the z-axis to minimize occlusion, each panel is then reiteratively segmented into a greater number of smaller sections until the depth profile is reduced to the maximum depth profile desired.

In accordance with the principles of the invention, it should be clearly understood, however, that to maintain the

apparent integrity of two-dimensional image 115 when texture-mapping the image onto the segmented sections, each segmented sections 205₁₋₄, 205₁₋₄', 210₁₋₄, and 210₁₋₄' is scaled accordingly with respect to the user's current viewpoint, V, so as to appear to be of the same size as the original corresponding section. This scaling or transform is given by:

$$S_t = S_p \frac{T_t}{T_p}$$

where S_p is the size of the original pyramidal section; S_t is the size of the translated, segmented pyramidal panel section; T_p is distance to the original pyramidal section from the user's viewpoint, V; and T_t is the distance to the translated, segmented pyramidal section. In other words, each segmented, translated section is scaled by the ratio T_t/T_p. Of course, as the user moves within the world, pyramidal panels 145₁₋₄' are accordingly re-segmented, translated, and then scaled with respect to the user's new viewpoint, V. Then, the images in original panels 145₁₋₄ are again accordingly texture-mapped into the corresponding translated sections 205₁₋₄, 205₁₋₄', 210₁₋₄, and 210₁₋₄' of the pyramidal panel structure.

In the above embodiments, distorting two-dimensional image 115 according to the movement of the user's viewpoint results in different portions of the image being accordingly "expanded" or "compressed" when texture-mapping image 115 onto the corresponding pyramidal panels, as

discussed above herein. Also, as the user's viewpoint moves along the z-axis closer to two-dimensional image 115, the image is accordingly scaled or "enlarged" to make objects in the image appear closer to the user. Note that doing so requires scaling the x and y components of the objects

accordingly as a function of their distance (z-axis) to the user's viewpoint. To illustrate these latter aspects of the present invention, shown in FIG. 16 is screen 110 with two-dimensional image 115 displayed therein having a resolution of M×N pixels, e.g., 1200×1200. Now, as shown in

FIG. 17, moving along the z-axis closer to the center of the image and then texture-mapping the corresponding portions of image 115 onto pyramidal panels 145₁₋₄' requires enlarging and distorting the image such that only a small center portion of the enlarged and distorted image is displayed on

screen 110, which in effect lowers the observable image resolution. This is so since the image only has a finite number of pixels, and fewer pixels are displayed on the same size screen. One solution to this latter problem is using high resolution images which allows the user to travel towards

the center of the image without losing image quality, but it results in the perimeter of the image having a resolution higher than needed since enlarging the image causes the perimeter of the image to be outside the field of view of the observer and, therefore not displayed on the screen. This

higher than needed resolution requires more memory to store image 115 as well as additional computational time to perform the texture mapping, among other things. Of course, using lower resolution images would require less memory and computational time, but it typically leads to poor image

quality near the center of image where the image is typically enlarged or distorted the greatest.

Referring to FIG. 18, there is shown still another embodiment of the present invention which obviates the aforementioned problem by using a two-dimensional image having a

"hierarchical image resolution," thereby allowing segmented portions of the image to have a resolution according to its location within the image. In this manner, a fine

resolution can be used for portions of image 115 near the center of the image whereas a coarse resolution can be used for the perimeter, thereby minimizing the total texture-map size or pixel-map size. It should be clearly understood that this hierarchical image resolution is equally applicable to any one of the above pyramidal panel structures discussed herein above. In this aspect of the present invention, two-dimensional image 115 has been segmented into resolution regions 215₁₋₄ each having a rectangular shape, although other shapes are readily adaptable for the purposes of this invention. The corresponding portions of image 115 within resolution regions 215₁₋₄ have different resolutions such that portions of the image closer to the center of the image have a finer resolution than portions farther away. For example, resolution regions 215₁₋₄ may have image pixel resolutions of $m_1 \times m_1$, $m_2 \times m_2$, $m_3 \times m_3$ and $m_4 \times m_4$, respectively, where $m_1 \geq m_2 \geq m_3 \geq m_4$. In this manner, distorting or enlarging portions of the image near the center of the image or where the image's vanishing point is typically located does not substantially affect the observed image resolution inasmuch as a greater number of pixels are contained in the image.

It is contemplated that the number of resolution regions that image 115 is segmented into as well as the pixel resolution therein may be, for example, chosen empirically based on image content as well as the user's range of movement within the virtual world. For example, portions of the image near the center can have a resolution of 4800x4800, while portions near the perimeter only a resolution of 1200x1200. Furthermore, the resolution for resolution regions 215₁₋₄ may be dynamically chosen according to the amount of distortion or enlargement performed on the image. That is, each region is allocated a finer resolution with a greater distortion or enlargement, and vice-a-versa.

Of course, various computer storage techniques may be used to set the image resolution within regions 215₁₋₄. For example, image 115, typically a still photograph, picture or video frame, may be captured with a resolution of 4800x4800 pixels or greater, and then a subset of those pixels used to achieve a desired lower resolution.

The foregoing merely illustrates the principles of the invention. It will thus be appreciated that those skilled in the art will be able to devise various arrangement which, although not explicitly describe or shown herein, embody the principles of the invention and are included within its spirit and scope.

What is claimed is:

1. A method for use in processing a view of a three-dimensional world in which a first portion of said world is modeled as computer graphics and a second portion of said world is represented by a two-dimensional image texture-mapped on a panel, said two-dimensional image including an object depicted in perspective, said image being such that features of the object closer to a predetermined point of the image are farther away from a user's viewpoint, comprising the steps of:

segmenting the two-dimensional image into a plurality of sections;

setting the pixel resolution of each of said plurality of sections according to its location within the two-dimensional image;

determining a vector, \bar{C} , corresponding to the direction of said perspective object in the three-dimensional world; projecting towards said panel the vector, \bar{C} , from the two-dimensional image's ideal viewing point, IVP, the intersection of said vector, \bar{C} , with the panel being denoted as the image's vanishing point, P;

segmenting said panel into triangular regions intersecting at the image's vanishing point, P;

determining the current viewpoint, V, of the user and projecting a vector, T, from the image's ideal viewing point, IVP, to the current viewpoint, V;

determining a new vanishing point for the two-dimensional image in accordance with the following relationship $P' = P + T$;

distorting the triangular regions in the space of the three-dimensional world such that they intersect at the new vanishing point, P';

texture-mapping the two-dimensional image in the triangular regions onto said distorted triangular regions; and displaying the computer graphics along with the two-dimensional image.

2. The invention as defined in claim 1 wherein the pixel resolution of each of said plurality of sections is set according to its location relative to the center of the two-dimensional image.

3. The invention as defined in claim 1 wherein the pixel resolution of each of said plurality of sections is set such that sections closer to the center of the two-dimensional image have a higher pixel resolution than sections farther away.

4. The invention as defined in claim 1 wherein each of said plurality of section is substantially rectangular in shape.

5. The invention as defined in claim 1 wherein the vanishing point is located at or near the center of the two-dimensional image.

6. A method for use in processing a view of a three-dimensional world in which a first portion of said world is modeled as computer graphics and a second portion of said world is represented by a two-dimensional image texture-mapped on a panel, comprising the steps of:

determining the current viewpoint of the user, V; dividing the panel into triangular regions;

distorting the triangular regions to form pyramidal panels such that a corresponding vanishing point, P, of a portion of the two-dimensional image moves as a function of the current viewpoint of the user;

segmenting each of said pyramidal panels into a plurality of sections;

translating each of said plurality of sections of said pyramidal panels towards, or away from, said current viewpoint of the user, V;

segmenting the two-dimensional image into sections; adjusting the pixel resolution in each of said sections of the two-dimensional image according to its location relative to the center of the two-dimensional image;

texture-mapping the two-dimensional image onto the plurality of sections of the pyramidal panels;

scaling each of said plurality of sections of said pyramidal panels in accordance with the following relationship $S_t = S_p T_p / T_t$, where S_p is the size of the section; S_t is the size of the translated section; T_p is distance to the section from the user's viewpoint, V; and T_t is the distance to the translated section from the user's viewpoint, V; and

displaying the computer graphics along with the two-dimensional image.

7. The invention as defined in claim 6 wherein the pixel resolution of each of said plurality of sections is set such that sections closer to the center of the two-dimensional image have a higher pixel resolution than sections farther away.

8. The invention as defined in claim 6 wherein each of said plurality of section is substantially rectangular in shape.

9. The invention as defined in claim 6 wherein said segmenting step includes resegmenting said pyramidal pan-

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els into a greater number of smaller sections until the depth profile of the pyramidal panel structure formed from said panels reaches a predetermined level.

10. The invention as defined in claim 6 wherein an outer edge of each of said plurality of sections of said pyramidal panels is located on the surface of a predetermined plane.

11. The invention as defined in claim 10 wherein said predetermined plane is the panel onto which the two-dimensional image is texture-mapped.

12. The invention as defined in claim 6 wherein the center of each of said plurality of sections of said pyramidal panels is substantially located at the surface of a predetermined plane.

13. The invention as defined in claim 12 wherein said predetermined plane is the panel onto which the two- 10

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14. The invention as defined in claim 6 further comprising determining a vector, \bar{C} , corresponding to the direction of a portion of a path contained within the two-dimensional image, and projecting toward the panel the vector, \bar{C} , from the image's ideal viewing point, IVP, the intersection of said vector, \bar{C} , with the panel being denoted as the image's vanishing point, P.

15. The invention as defined in claim 6 wherein said distorting of the triangular regions in said distorting step includes determining a new vanishing point, P', for said two-dimensional image in accordance with the following relationship $P' = P + \bar{T}$, wherein \bar{T} is a vector from the image's ideal viewing point, IVP, to the current viewpoint, V.

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US006236402B1

(12) **United States Patent**
Edmark

(10) Patent No.: **US 6,236,402 B1**
(45) Date of Patent: **May 22, 2001**

(54) **DISPLAY TECHNIQUES FOR
THREE-DIMENSIONAL VIRTUAL REALITY**

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patent is extended or adjusted under 35
U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/160,758**

(22) Filed: **Sep. 25, 1998**

Related U.S. Application Data

(63) Continuation-in-part of application No. 09/107,059, filed on
Jun. 30, 1998.

(51) Int. Cl.⁷ **G06T 17/00**

(52) U.S. Cl. **345/419; 345/427**

(58) Field of Search **345/418, 419,
345/420, 427, 433, 139, 473, 474**

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ABSTRACT

A limitation of using two-dimensional images, such as videos or photographs, to represent portions of a three-dimensional world occurs when the user moves within the world and views the world from a location different than from the original context of the two-dimensional image, i.e., from a location different than the image's ideal viewing point (IVP). View changes result in the image not aligning well with the surrounding objects of the three-dimensional world. This limitation is overcome by distorting the two-dimensional image so as to adjust the image's vanishing point(s) in accordance with the movement of the user using a pyramidal panel structure. In this manner, as the user moves away from the ideal viewing point, the distortions act to limit the discontinuities between the two-dimensional image and its surroundings. To minimize the depth profile of the pyramidal panel structure, the structure may be segmented into sections and each section translated towards, or away from, the user's viewpoint.

32 Claims, 12 Drawing Sheets

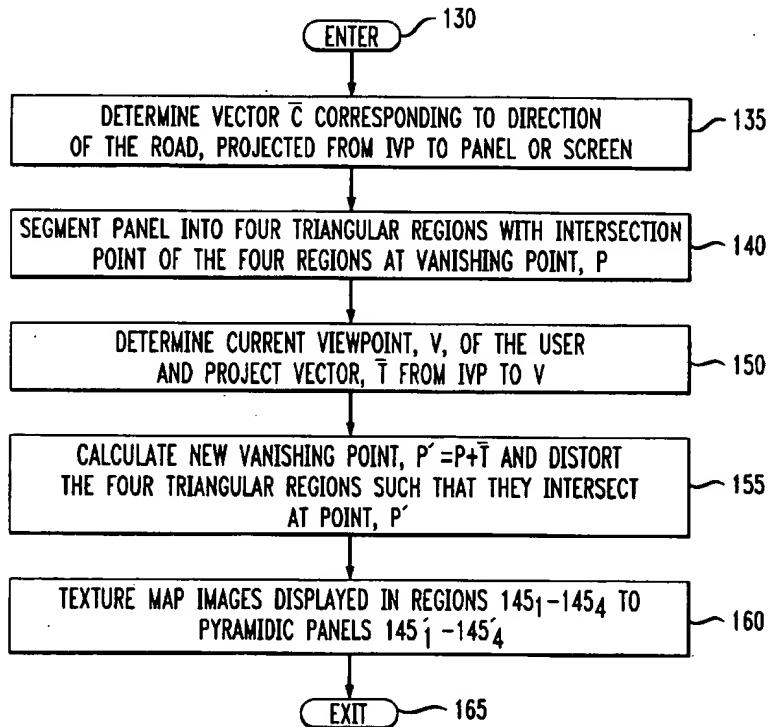


FIG. 1

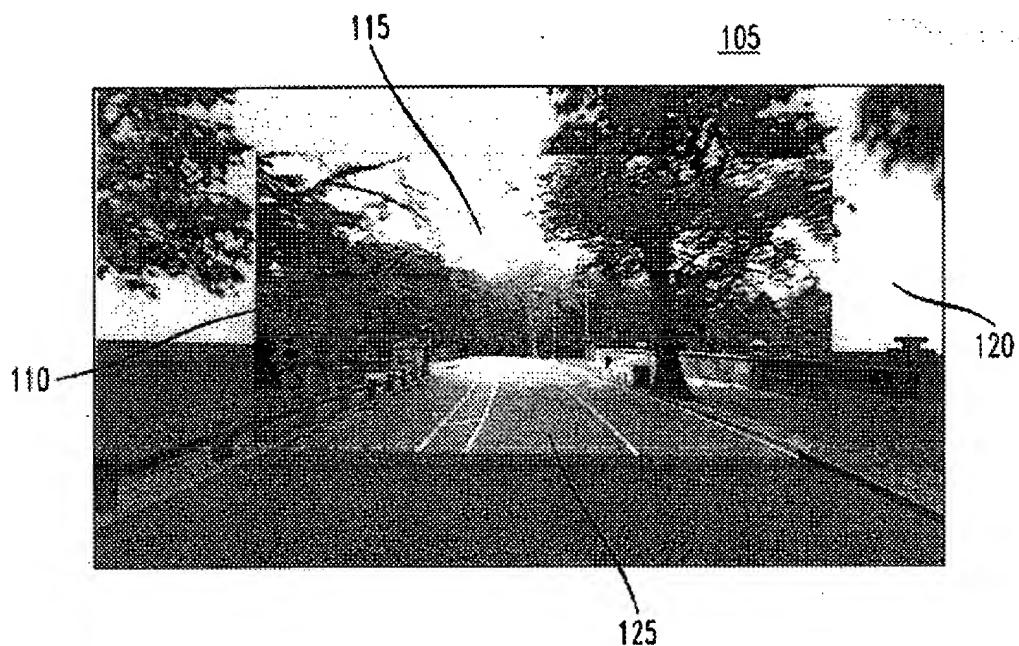


FIG. 2

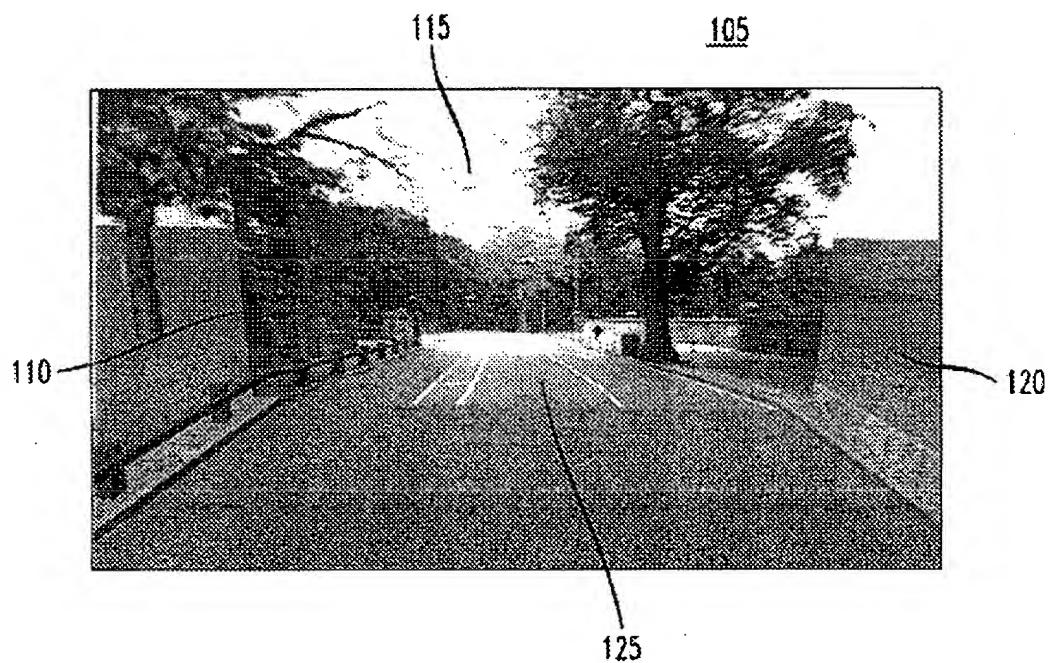


FIG. 3

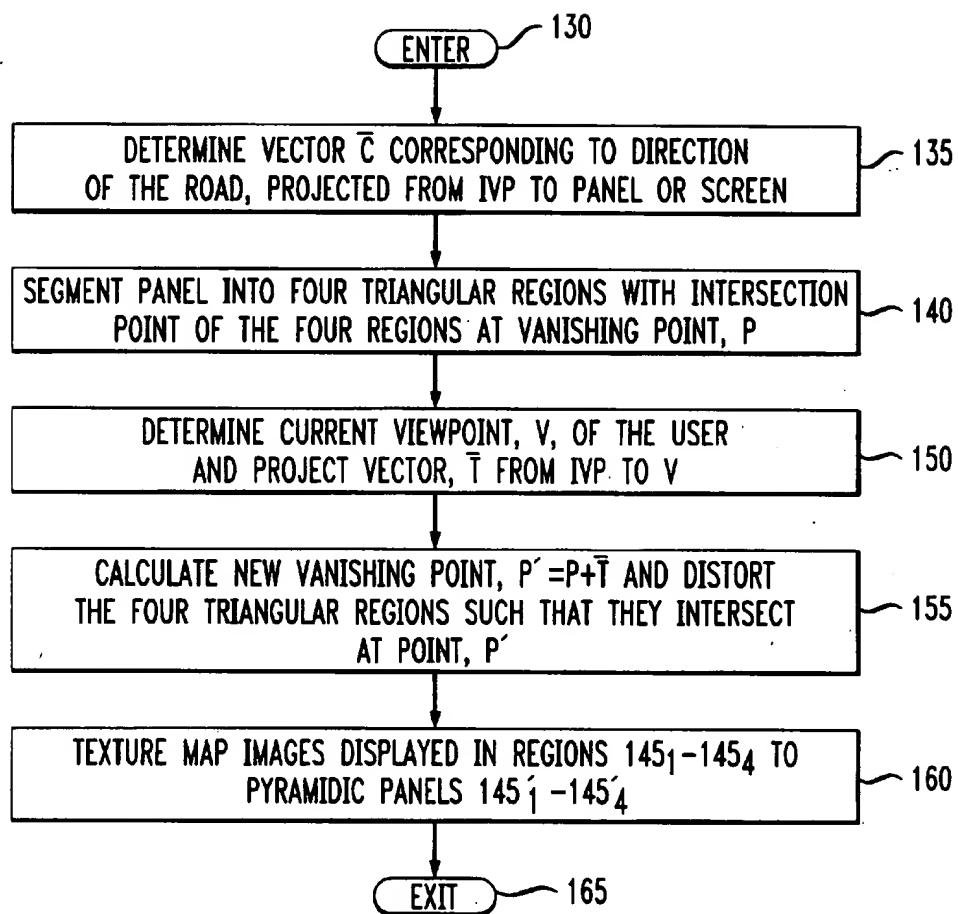


FIG. 4

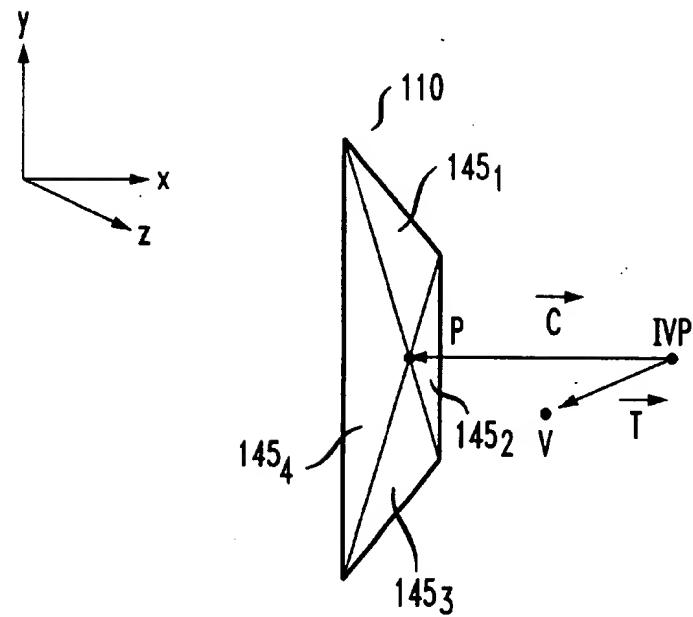


FIG. 5

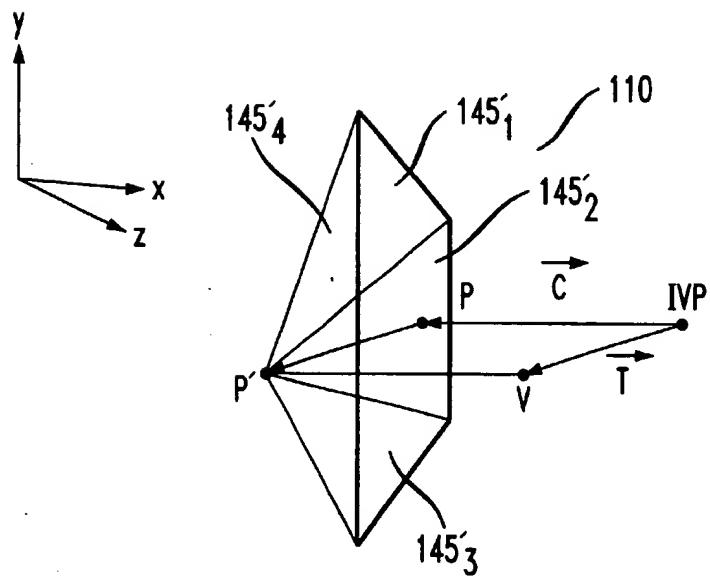


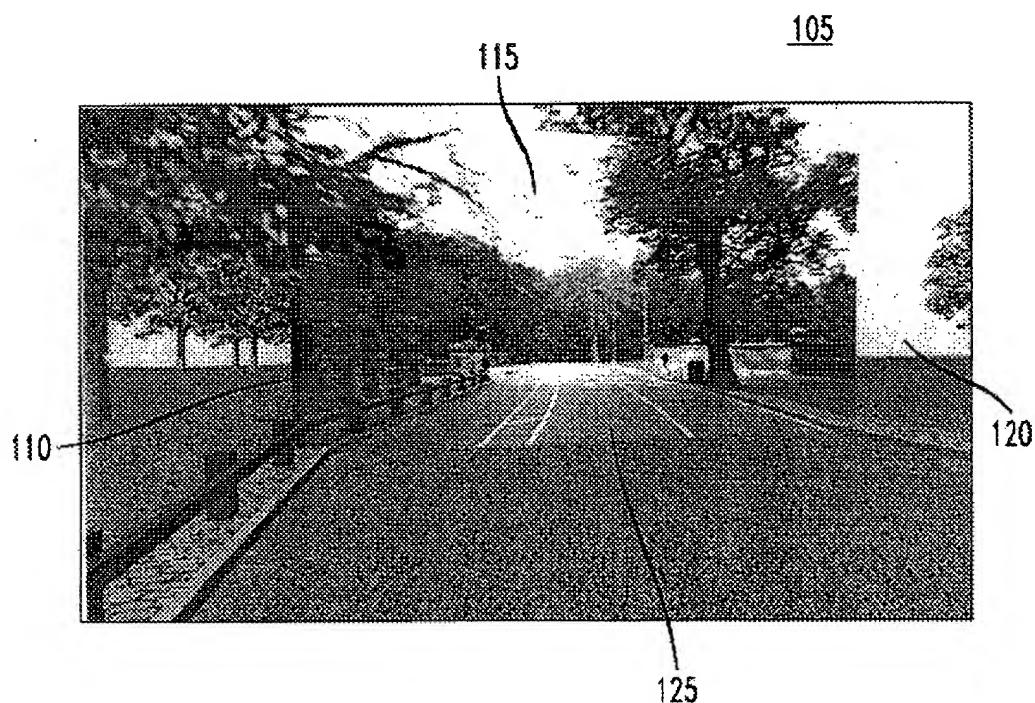
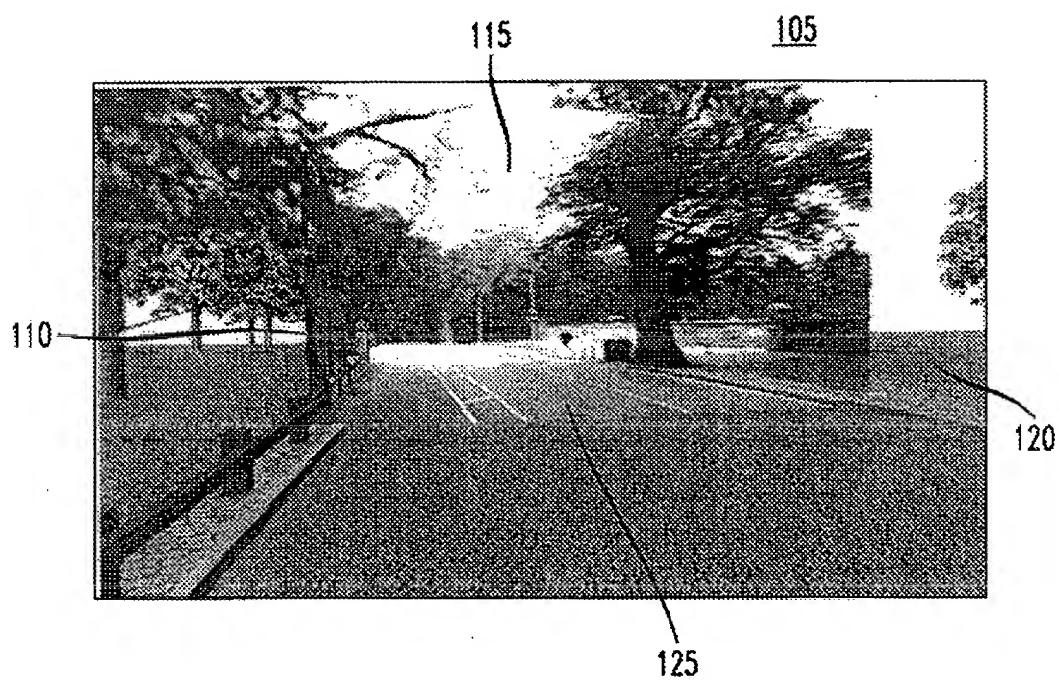
FIG. 6A*FIG. 6B*

FIG. 7A

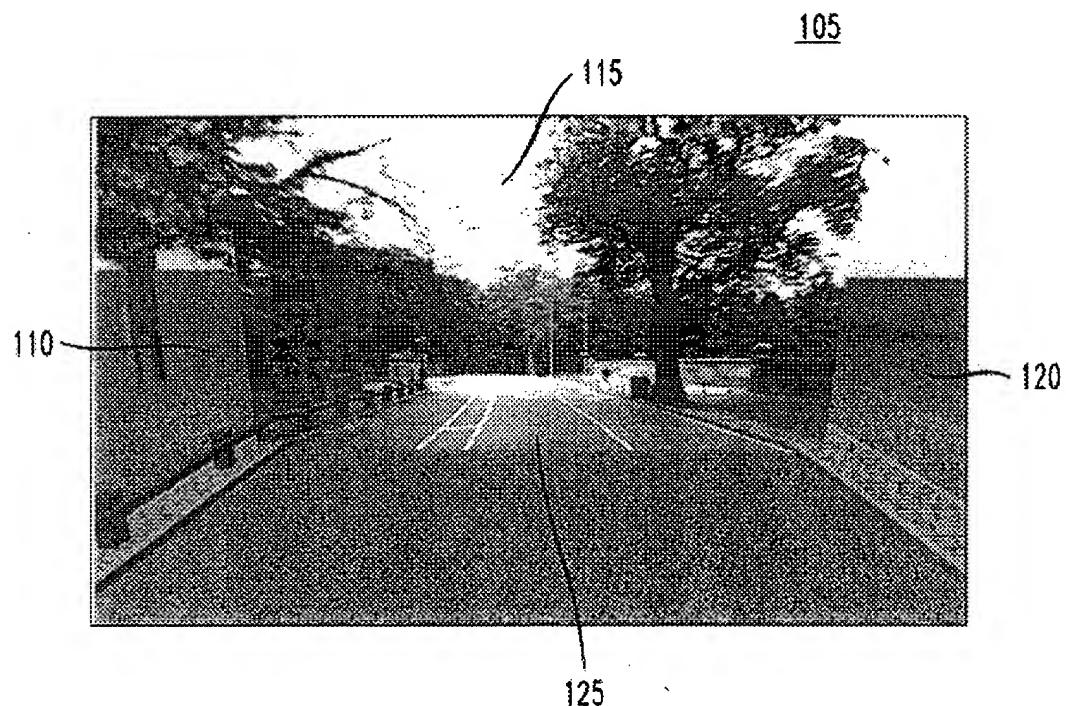
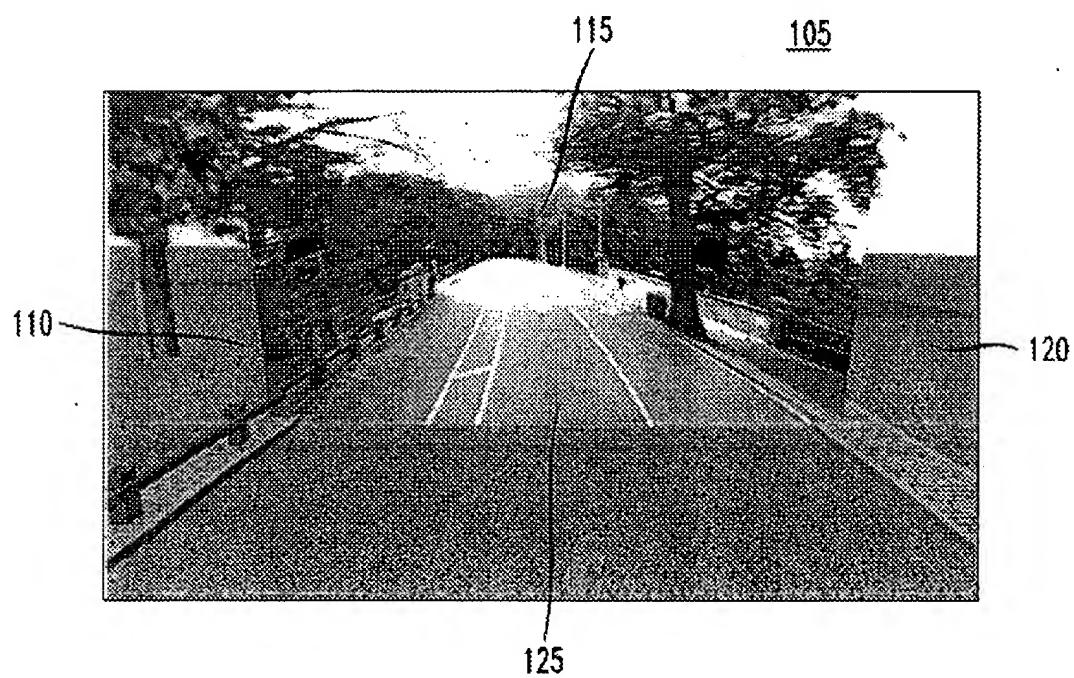


FIG. 7B



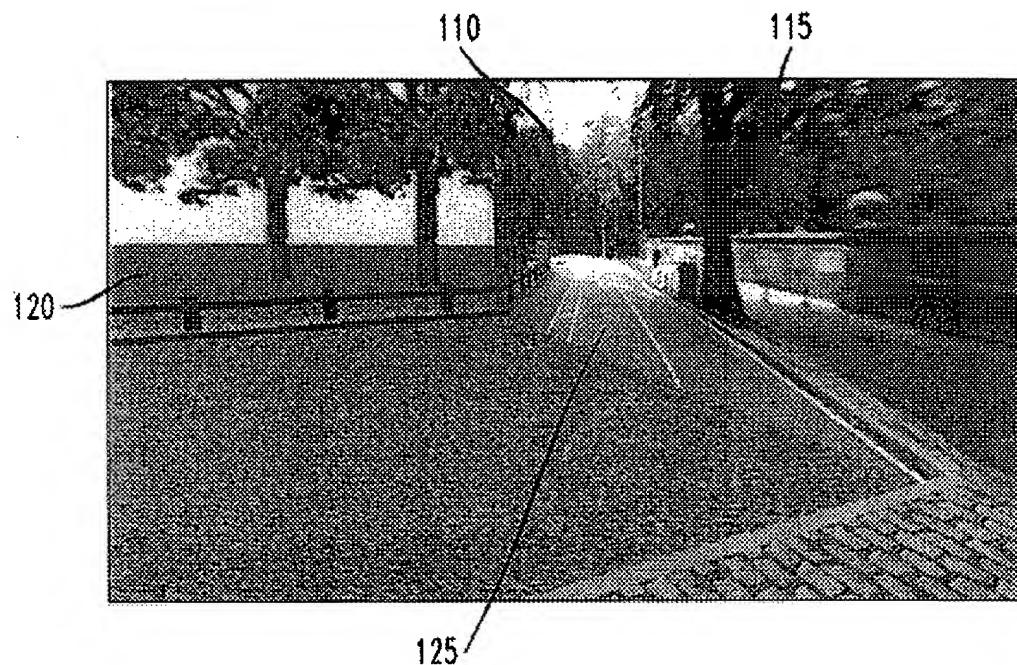
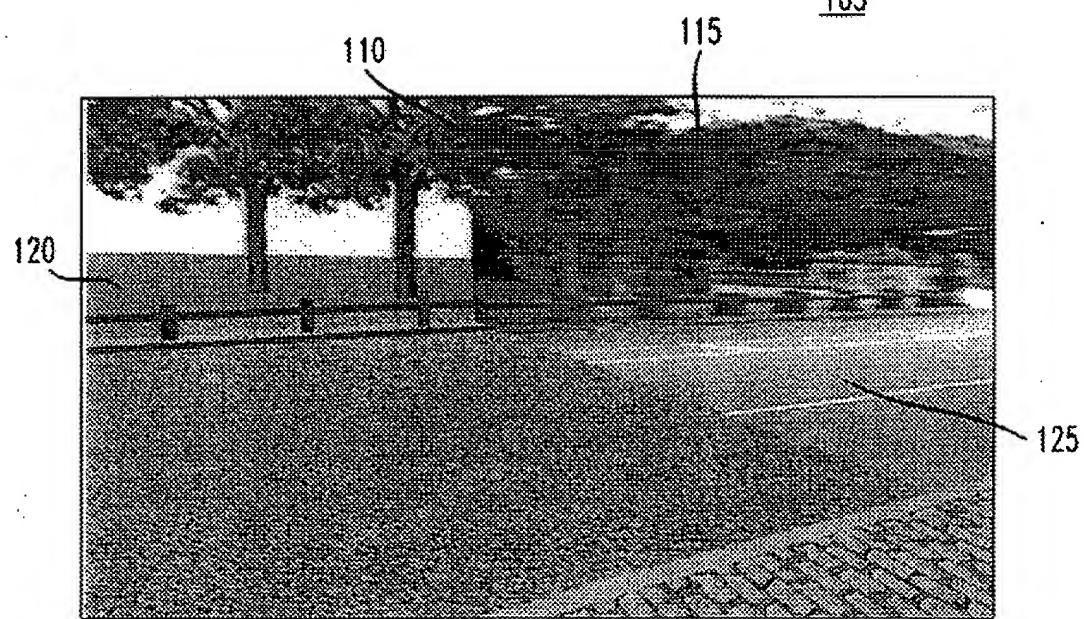
*FIG. 8A*105*FIG. 8B*105

FIG. 9

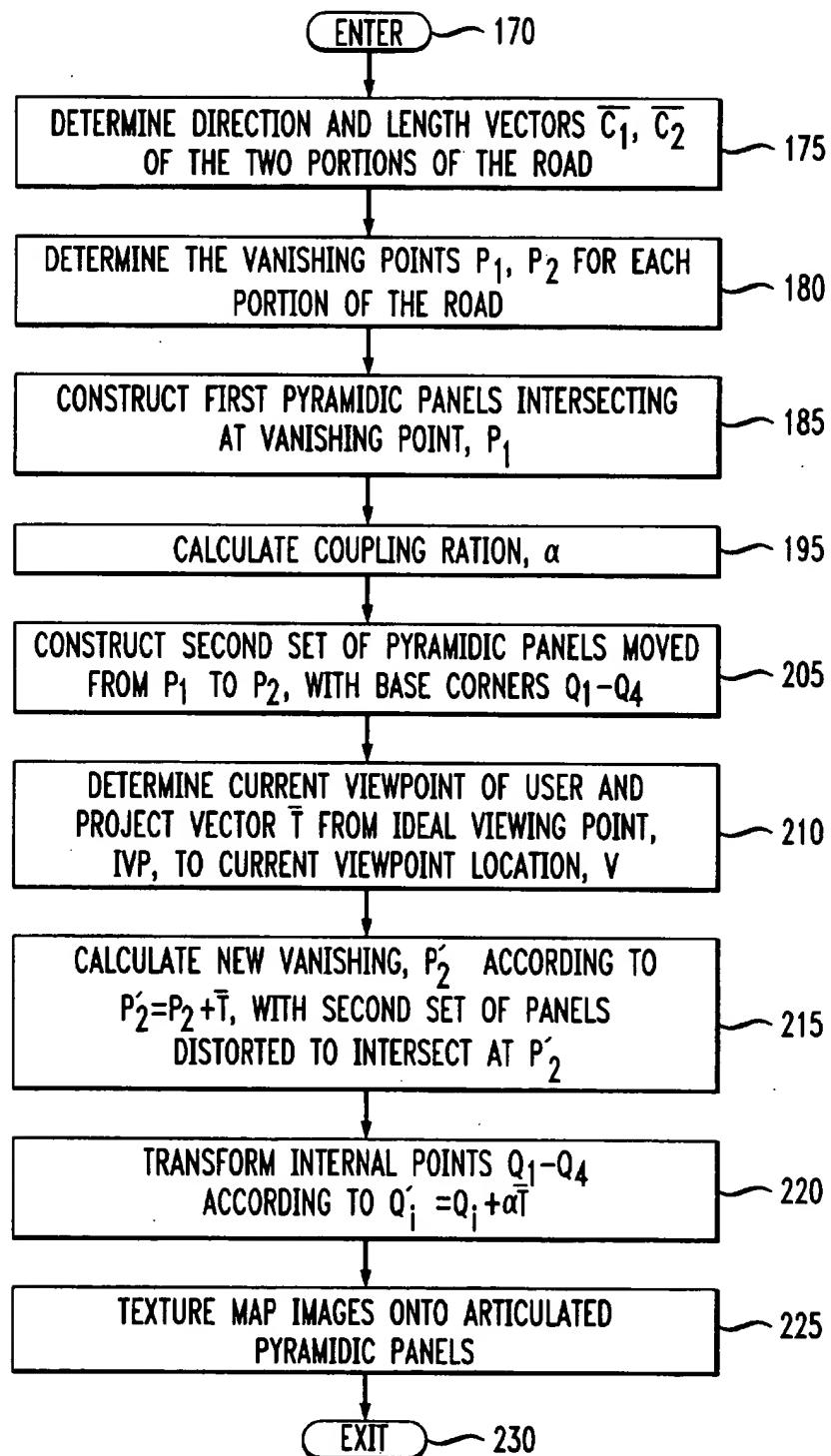


FIG. 10

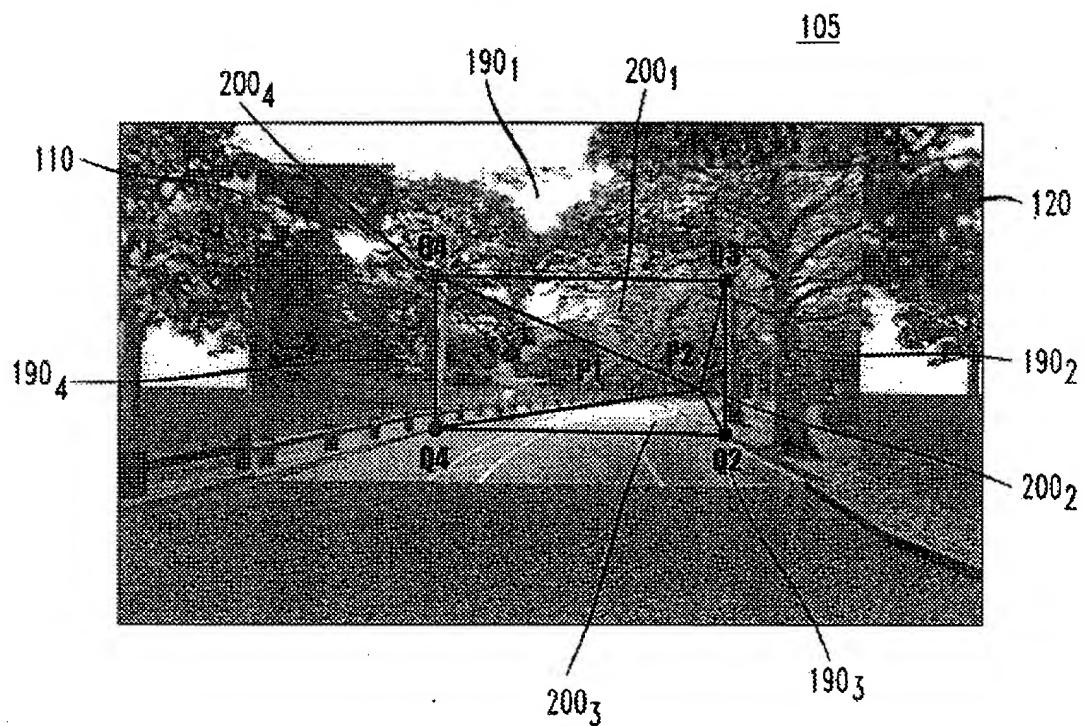


FIG. 11

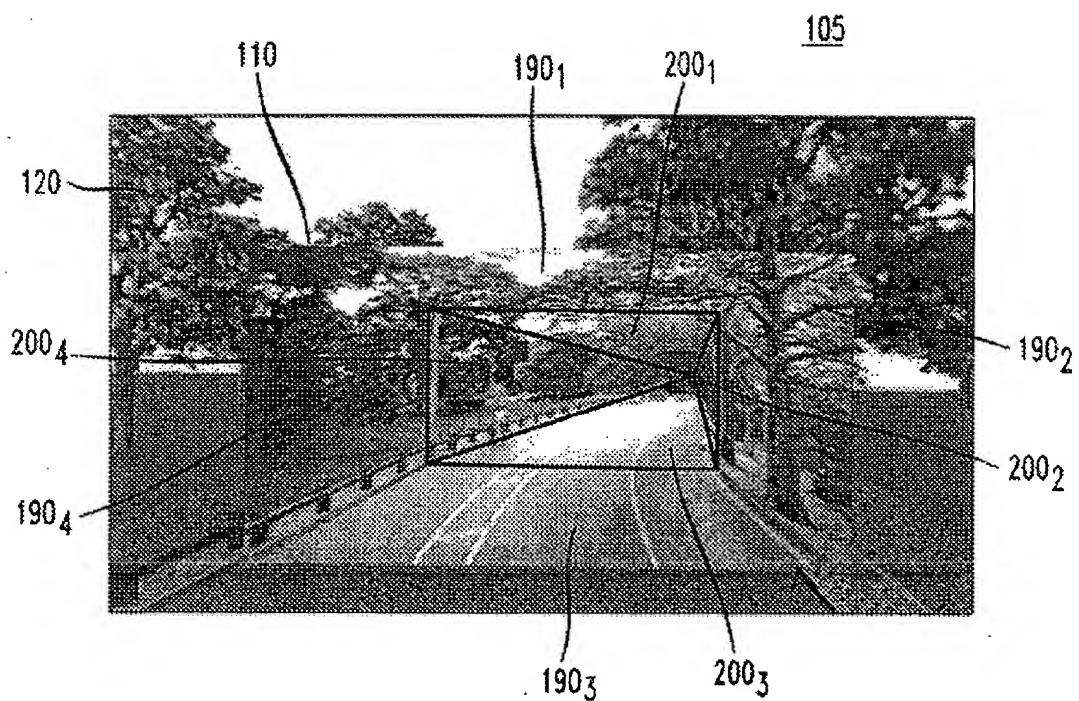


FIG. 12

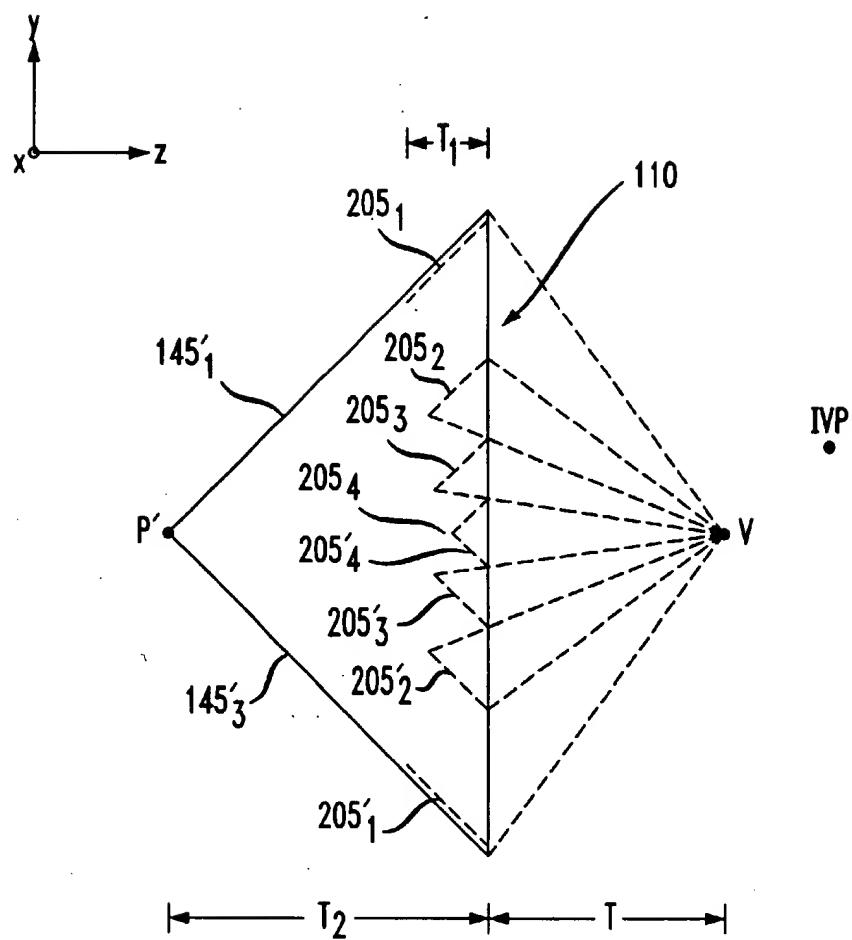


FIG. 13

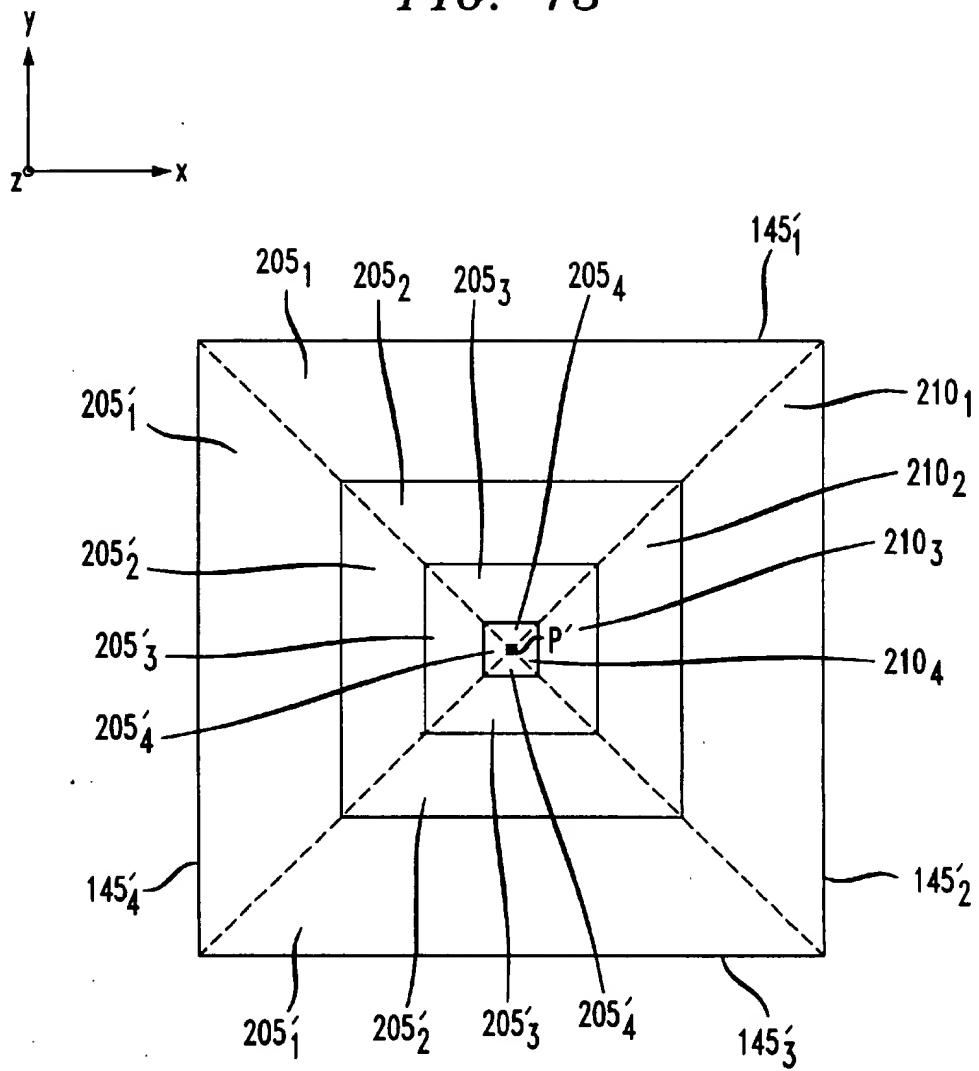
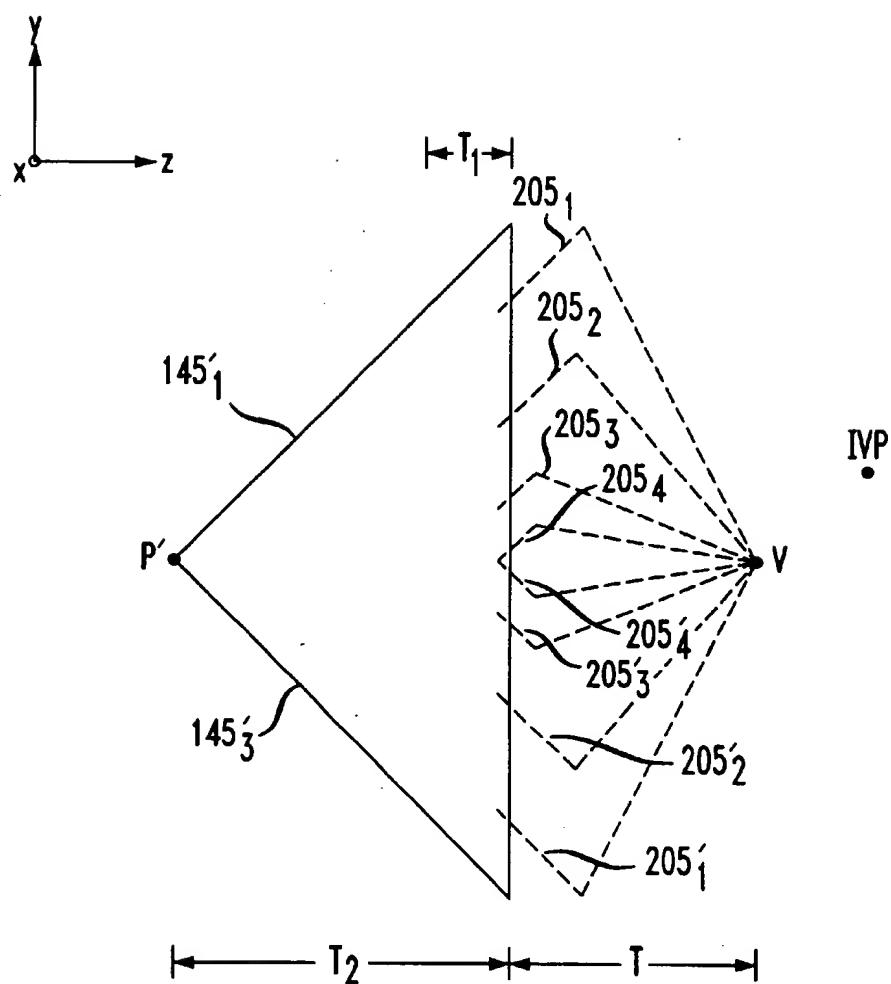


FIG. 14



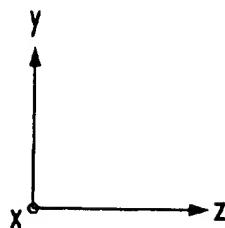
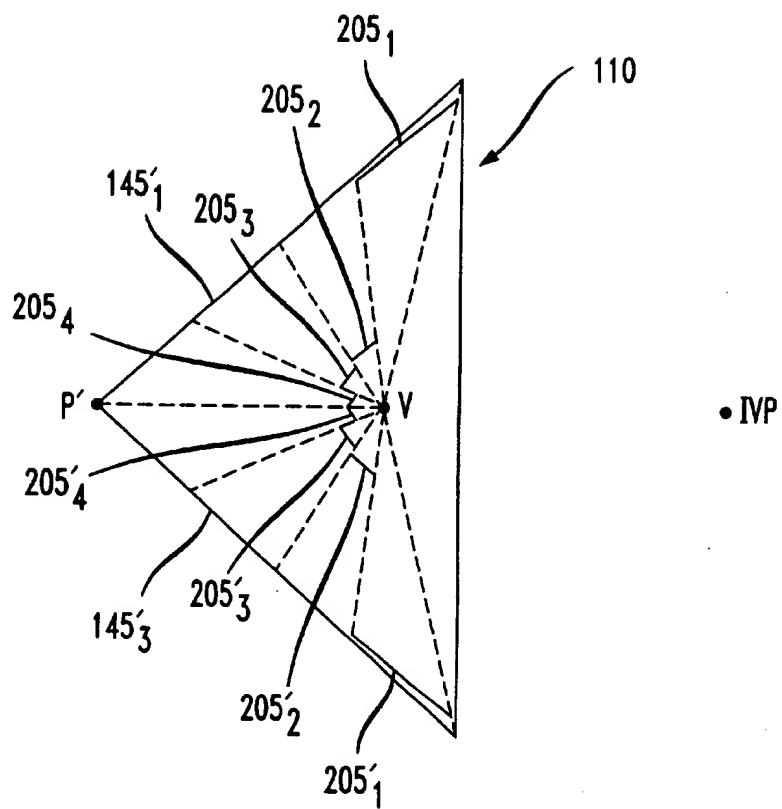


FIG. 15



DISPLAY TECHNIQUES FOR THREE-DIMENSIONAL VIRTUAL REALITY

CROSS-REFERENCE TO RELATED APPLICATION

This application is a continuation-in-part of U.S. patent application Ser. No. 09/107,059 filed on Jun. 30, 1998 (Case Edmark-2). The above-identified co-pending application, which is commonly assigned, is incorporated herein by reference.

TECHNICAL FIELD

This invention relates to the integration of three-dimensional computer graphics and a two-dimensional image to provide a realistic three-dimensional virtual reality experience.

BACKGROUND OF THE INVENTION

The display of a three-dimensional virtual reality world to a user requires considerable computation power, and it is typically costly to develop the necessary highly detailed models required for doing so. In order to simplify the problem, two-dimensional images, such as videos or photographs, may be used to represent or simulate portions of the three-dimensional world. A great reduction in computation power and cost can be achieved by such an arrangement.

SUMMARY OF THE INVENTION

A limitation of such a world occurs when a user moves within the world and views the world from a location different than the original context of a two-dimensional image which has been carefully calibrated to "fit into" the world. View changes, such as from a location different than the image's ideal viewing point, result in the image not aligning or fitting well with the surrounding objects of the three-dimensional world. We have recognized that, in accordance with the principles of the invention, viewpoint changes may be dealt with by distorting the two-dimensional image so as to adjust the image's vanishing point(s) in accordance with the movement of the user using a novel "pyramidal panel structure." In this manner, as the user moves away from the ideal viewing point, the distortions act to limit the discontinuities between the two-dimensional image and the surroundings of the world. In certain embodiments, the pyramidal panel structure may be segmented into sections, each translated towards or away from the user's viewpoint and then scaled, so as to minimize the depth profile of the pyramidal panel structure.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings:

FIG. 1 shows an example of that which a user sees when a user views the world from the ideal viewing point for a two-dimensional image representing a portion of the world;

FIG. 2 shows an example of that which a user sees when a user moves within the world of FIG. 1 and views the two-dimensional image from a location different than the image's ideal viewing point, without the use of the present invention;

FIG. 3 shows an exemplary process, in accordance with the principles of the invention, for distorting the two-dimensional image using a pyramidal panel structure so as to adjust the image's vanishing point in accordance with the movement of the user;

FIGS. 4 and 5 depict the pyramidal panel structure of the present invention for distorting the two-dimensional image so as to adjust the image's vanishing point, in accordance with the movement of the user;

FIGS. 6A-B depict examples of that which a user sees when a user views the world from a location left of the image's ideal viewing point, without and with the use of the present invention, respectively;

FIGS. 7A-B depict examples of that which a user sees when a user views the world from a location above the image's ideal viewing point, without and with the use of the present invention, respectively;

FIGS. 8A-B depict examples of that which a user sees when a user views the world from a location toward the front and the right of the image's ideal viewing point, without and with the use of the present invention, respectively;

FIG. 9 shows an exemplary process, in accordance with the principles of the invention, for distorting a two-dimensional image using an articulated pyramidal panel structure so as to adjust multiple vanishing points in the image, in accordance with the movement of the user;

FIG. 10 depicts an example of the articulated pyramidal panel structure of the present invention;

FIG. 11 depicts an example of that which a user sees when a user views the world from a location away from the ideal viewing point of the two-dimensional image, with the use of the articulated pyramidal panel structure of the present invention;

FIGS. 12 and 13 depict side and front views, respectively, of the pyramidal panel structure of FIG. 5 with each panel segmented into a plurality of sections;

FIG. 14 depicts the pyramidal panel structure of FIG. 5, with each panel segmented into a plurality of sections having its centers located on the surface of a predetermined plane; and

FIG. 15 depicts the pyramidal panel structure of FIG. 5, with each panel segmented into a plurality of sections and each section translated a different distance toward the user's view point, V.

DETAILED DESCRIPTION

To better understand the invention, FIGS. 1-2 show examples of that which a user sees when the user moves within a three-dimensional virtual reality world (x,y,z) and views a two-dimensional image (x,y) representing a portion of the world from a location at the image's ideal viewing point (IVP), and then from a different location, i.e., a location different than the original context of the image. It should be understood that the two-dimensional image has been carefully calibrated to "fit into" the surroundings of the world. For simplification of terminology purposes, we shall use the term two-dimensional image to denote either a video clip or a photograph. In accordance with the principles of the invention, as the user moves away from the ideal viewing point, discontinuities between the two-dimensional image and its surroundings are minimized by distorting the image according to the movement of the user.

FIG. 1 shows an exemplary three-dimensional reality world 105, which is a bicycle path in a park, e.g., Central Park in New York City. In representing world 105, the present invention exploits a characteristic common for images consisting of views looking down the center of roads, streets or paths, which is that they may be treated as perspective, corridor-like images, with features closer to the center of the image being farther away from the viewer

along the z-axis. Accordingly, the bicycle path or road and its immediate vicinity are treated as a kind of three-dimensional, corridor-like image whose floor is formed by the roadbed, whose ceiling is formed by the sky, and whose sidewalls are formed by the roadside objects. In this manner, the principles of a simple point perspective can be used for distorting the landscape image in accordance with the movement of the viewer, as discussed herein below.

World 105 is divided into two portions, screen or panel 110 on which is shown or displayed a two-dimensional image 115, such as a still photograph, picture, or a current frame of a video clip; and the remainder of the world 120, which is represented using computer graphics techniques, and is thus referred to herein as computer graphics (CG Part) 120. Within CG Part 120 there are various synthetic, three-dimensional landscapes or objects modeled in, for example, the Virtual Reality Modeling Language (VRML). Two-dimensional image 115 simulates landscape or terrain portions of the world 105, here a virtual road or course 125 for walking, running or pedaling a bicycle.

Note that although three-dimensional world 105 cannot be actually rendered in a two-dimensional plane (x,y), it can be projected to and displayed on a two-dimensional plane so as to appear to have three dimensions (x,y,z). Accordingly, the techniques of the present invention are preferably employed with computers and software, which are sufficiently sophisticated to display images on a two-dimensional plane as having three dimensions. Note also that to make the world look realistic, computer graphics display techniques use the z component of objects to scale accordingly the x and y components as a function of its distance (z-axis) to the user's viewpoint.

Two-dimensional image 115 is carefully placed, cropped and sized to achieve continuity with the surrounding environment of the CG Part 120. Note that the image is clipped so that the left and right edges of the road in CG Part 120 pass through the left and right bottom corners of the road, respectively, in image 115. This clipping ensures that the roadbed maps to the floor of the hypothetical corridor. In so doing, portions at the boundary between two-dimensional image 115 and CG part 120 are co-planar, i.e., at the same distance away along the z-axis from the user's viewpoint. In "fitting" two-dimensional image 115 to CG part 120, however, there exists only one viewpoint from which that image's content properly corresponds to the surrounding environment of CG Part 120. This unique location is called the image's ideal viewing point (IVP). In FIG. 1, two-dimensional image 115 is seen from its ideal viewing point, and from this view, image 115 aligns well with the surrounding objects of CG Part 120.

Users, however, rarely view image 115 only from its ideal viewing point. As the user moves within world 105, such as left or right of road 125, as they round curves, or move closer to or farther from the image, they see image 115 from positions other than its ideal viewing point. Absent the use of the present invention, such viewpoint changes would cause objects or features within image 115 to align improperly with the surrounding environment, as further illustrated in FIG. 2.

In accordance with the principles of the invention, however, screen or panel 110 uses a display structure called a "pyramidal panel structure" for displaying two-dimensional image 115 within the surrounding three-dimensional space of the CG Part 105 so as to deal with viewpoint changes. The transformations associated with the pyramidal panel structure dynamically distort two-

dimensional image 115 according to viewer's position so as to adjust the image's vanishing point with the viewer's movement. As the viewer moves from the image's ideal viewing point, these distortions act to limit discontinuities between image 115 and the surroundings of CG Part 120.

FIG. 3 shows an exemplary process in accordance with the principles of the invention for distorting two-dimensional image 115 so as to adjust its vanishing point in accordance with the viewer's position. The process is entered at step 130 whenever it is determined that the viewer's position has changed.

Using the virtual world's road model of the CG Part 105, a vector, \vec{C} , corresponding to the direction of road 125 is projected at step 135 from the image's ideal viewing point, IVP, to panel or screen 110 on which is displayed image 115. Note that the panel is two-dimensional, but represents three-dimensional space with objects nearer the center of the image being farther away from the plane of the viewer. The panel structure is shown in FIG. 4. The point of intersection with screen or panel 110 is the image's vanishing point, P. Note, however, that the vanishing point may be set visually by the user, if desired, or by other suitable computer graphics processing techniques known in the art. Next, in step 140, screen or panel 110 is segmented into four triangular regions 145₁₋₄, one for each of the regions bordering CG Part 120, with the intersection point of the four regions located at the vanishing point, P.

Thereafter in step 150, the current viewpoint of the user, V, is determined, and a vector \vec{T} projected from the ideal viewing point, IVP, to the viewer's current location, V. In accordance with the principles of the invention, as the viewer moves, a new vanishing point P' is calculated as $P' = P + \vec{T}$. The four triangular regions 145₁₋₄ are distorted in the three-dimensional space of the virtual world at step 155 to represent the mapping of objects nearer the center of the image being displaced farther away from the viewpoint of the user. The four triangular regions intersect at the new vanishing point P' and form so-called "pyramidal panels" 145'₁₋₄. This is illustrated in FIG. 5. At step 160, the corresponding images displayed in regions 145₁₋₄ are then "texture-mapped" onto pyramidal panels 145'₁₋₄, respectively. In this manner, as the viewer moves away from the image's ideal viewing point, IVP, distortions in the image resulting from moving the image's vanishing point from P to P' act to limit the discontinuities between image 115 and the surroundings within CG Part 105.

In the exemplary illustration of FIG. 5, distorting image 115 so as to move the vanishing point from P to P' results in pyramidal panel structure forming a four-sided pyramid. Note that its base is fixed and corresponds to original screen or panel 110, with its peak located at P', which moves in concert with the viewer's current location, V. As the user's viewpoint moves closer to and farther from the image, the image's vanishing point accordingly moves farther from and closer to the user's viewpoint, respectively.

FIGS. 6 through 8 compare the display of two-dimensional image 115 on screen or panel 110 with the display of the same image using the "pyramidal" panels of the present invention. More specifically, FIGS. 6A, 7A and 8A depict viewing two-dimensional image 115 at a location from the left, above, and in front and to the right of the image's ideal viewing point, IVP, respectively, without the use of the present invention. In these latter figures, note that there are discontinuities between the edges of the road and the three-dimensional space of CG Part 105. FIGS. 6B, 7B and 8C depict the same two-dimensional image distorted

and texture-mapped onto pyramidal panels $145'_{1-4}$, in accordance with the principles of the invention. Note that in these latter figures, the discontinuities in the road edge have been substantially eliminated.

In another embodiment of the present invention, a modified pyramidal panel structure may be used to deal with two-dimensional images containing curved roads, streets, paths and other corridor-like images containing multiple rather than a single vanishing point. In this latter case, screen or panel 110 is segmented using multiple vanishing points to form a so called "articulated pyramidal panel structure." The transformations associated with the articulated pyramidal panel structure dynamically distort different portions of two-dimensional image 115 according to viewer positions so as to adjust the different vanishing points of the image with the viewer's movement. Likewise, as the viewer moves from the image's ideal viewing point, these distortions act to limit the discontinuities between two-dimensional image 115 and the surroundings of CG Part 120 .

FIG. 9 shows an exemplary process in accordance with the principles of the invention for distorting two-dimensional image 115 using an articulated pyramidal panel structure. Again, the process is entered at step 170 whenever it is determined that the viewer's position has changed. In general, curve road 125 is treated as two straight corridors placed end-to-end, extending back from screen or panel 110 . Each corridor represents a different portion of road 125 in the three-dimensional space of world 105 , with features nearer the center of the image being farther away from the user's viewpoint.

Using the virtual world's road model of the CG Part 105 , corresponding directional vectors C_1 and C_2 of the corridors are determined at step 175 . Note that portion of the road nearer to the user's viewpoint is represented by C_1 , and the portion farther away is represented by C_2 . Next, in step 180 , using the vectors C_1 and C_2 , the corresponding vanishing points P_1 and P_2 are determined, respectively, for each corridor by projecting those vectors from the image's ideal viewing point, IVP. Alternatively, vanishing points P_1 and P_2 may be determined visually by the user, or by some other suitable means known in the art. In step 185 , using the first corridor's vanishing point, P_1 , a first set of pyramidal panels 190_{1-4} are constructed to intersect at vanishing point, P_1 , as shown in FIG. 10.

Now at step 195 , a coupling ratio α is calculated according to the following equation: $\alpha=1/(1+d)$, where 1 is the length of the first corridor, and d is the distance between the image's ideal view point (IVP) and the base of pyramidal panels 190_{1-4} . Each line segment connecting a corner of the base to vanishing point P_1 is then divided into two segments by a point placed according to the coupling ratio, α . More specifically, the length l' of each line segment from the corner of the base of panels 190_{1-4} to this point is given by $l'=al'$, where l' is the total length of the segment between the corner of the panel and the vanishing point, P_1 . These four points labeled Q1 through Q4 are connected to form the base of a second set of smaller pyramidal panels 200_{1-4} embedded within the larger panels (step 205), as further illustrated in FIG. 10. The intersection point of pyramidal panels 200_{1-4} is then moved from P_1 to vanishing point, P_2 .

For the articulated pyramidal panel structure, the current viewpoint of the user, V , is determined, and a vector T projected from the ideal viewing point, IVP, to the viewer's current location, V (step 210). As the viewer moves, a new vanishing point P'_2 is calculated as $P'_2=P_2+T$ at step 215 , and panels 200_{1-4} are then distorted so as to intersect at P'_2 . As

the viewer move, the four internal points Q1 through Q4 are mapped with the viewer's movement to Q1' through Q4', respectively, in accordance with the following relationship: $Q'_i=Q_i+\alpha T$, at step 220 . Note that doing so, accordingly distorts the first set of pyramidal panels 190_{1-4} . At step 225 , the corresponding images in original panels are then texture-mapped into articulated pyramidal panels 190_{1-4} and 200_{1-4} , which have been distorted in accordance with the movement of the viewer. Note that to unambiguously texture-map onto panels 190_{1-4} , these panels are each subdivided into two triangular subregions and then texture-mapped. Shown in FIG. 11 is image 115 seen from a location away from the image's ideal viewing point, using the articulated pyramidal panel structure of the present invention.

Note that the above articulated pyramidal panel structure may also use more than two sets of pyramidal panel structures. Instead of treating the curve road as two straight corridors, multiple corridors may be employed, each placed end-to-end and extending back from screen or panel 110 . Likewise, each corridor represents a different portion of road 125 in the three-dimensional space of world 105 , with features nearer the center of the image being farther away from the user's viewpoint. In such a case, each set of articulated pyramidal panels are formed reiteratively using the above described procedure.

Referring to FIGS. 12-13, there is shown a third embodiment of the present invention which is similar to that of FIG. 5 and in which "pyramidal panels" $145'_1$, $145'_2$, $145'_3$ and $145'_4$ have been now multi-segmented into sections 205_{1-4} , 210_{1-4} , $205'_{1-4}$, and $210'_{1-4}$, respectively, with the images in original panels 145_{1-4} then texture-mapped into the corresponding translated sections of the pyramidal panel structure, as discussed herein below. It should be recalled that the pyramidal panel structure represents the three-dimensional mapping (x,y,z) of two-dimensional image 115 onto image screen or panel 110 (x,y) . Advantageously, the embodiment of FIGS. 12-13 minimizes the depth profile of the pyramidal panel structure along the z -axis. Unlike the embodiment of FIG. 5, the depth profile of this third embodiment does not substantially vary with changes in the user's viewpoint, V . In the exemplary embodiment of FIG. 5, recall that distorting image 115 so as to move the vanishing point from P to P' results in the pyramidal panel structure forming a four-sided pyramid. The base of the pyramid is fixed and corresponds to original screen or panel 110 , with its peak located at P' and moves in concert with the viewer's current location, V . As the user's viewpoint moves along the z -axis closer to and farther from two-dimensional image 115 , the image's new vanishing point P' moves farther from and closer to the user's viewpoint, respectively. This latter movement causes the depth profile along the z -axis of the pyramidal panel structure to vary accordingly. Unfortunately, this variation in depth profile can undesirably and/or unexpectedly occlude from the user's view objects in the virtual world, or cause objects to occlude other features in the virtual world inasmuch as the corresponding images in the panels are distorted, as discussed above herein.

To obviate the aforementioned problem, "pyramidal panels" $145'_1$, $145'_2$, $145'_3$ and $145'_4$ have been multi-segmented into sections 205_{1-4} , 210_{1-4} , $205'_{1-4}$, and $210'_{1-4}$ respectively. Each section is then translated along the z -axis to a predetermined distance towards or away from the user's viewpoint, V , but importantly of the same orientation as the original section. For example, segmented sections 205_{1-4} and $205'_{1-4}$ may each have one of its outer edge along the x -axis translated to lie on the x,y plane of screen or panel 110 , as shown in phantom in FIG. 12. As the user moves to

a new viewpoint, each section in effect pivots about that edge along the x-axis, which edge lies on the surface of panel 110. Similarly, section 210₁₋₄ and 210'₁₋₄ may each have one of its outer edge along the y-axis lying on the surface of panel 110. Alternatively, sections 205₁₋₄, and 205'₁₋₄ may be centered along panel 100, as depicted in FIG. 14. Likewise, sections 210₁₋₄ and 210'₁₋₄ may be similarly translated, but for the sake of clarity are not shown in FIGS. 12 and 14.

Still further, each of sections 205₁₋₄ and 205'₁₋₄ may in effect be rotated or pivoted about its other edge along the x-axis as the user moves to a new viewpoint, V, or, in general, about an axis parallel with an edge along the x-axis of the corresponding section. Again, this latter axis may, but does not have to, lie on the surface of panel 110. Regardless of the segmenting method chosen, however, translating each section towards or away from the user's viewpoint significantly reduces the depth profile of the pyramidal panel structure along the z-axis, such as depicted in FIG. 12 from, for example, T₂ to T₁.

In still another embodiment of the present invention, sections 205₁₋₄ and 205'₁₋₄ may each be translated a different distance along the z-axis, as illustrated in FIG. 15. Although not shown, sections 210₁₋₄ and 210'₁₋₄ may likewise be translated. Those skilled in the art will readily understand that doing so advantageously allows the user's viewpoint, V, to extend in front of panel 110 inasmuch as segmented sections corresponding to the image's center may be offset and located closer to the user's viewpoint, V, than the outer sections.

Also, note that segmenting the pyramidal panel structure into a greater number of smaller sections accordingly only further reduces the depth profile, which asymptotically approaches a zero thickness. It is contemplated that the number of sections that the panel structure is divided into may be chosen empirically based on image content as well as the user's range of movement within the virtual world. Preferably, however, the panel structure is dynamically segmented in a reiterative manner. For example, once a user has chosen the maximum desired depth for the panel structure along the z-axis to minimize occlusion, each panel is then reiteratively segmented into a greater number of smaller sections until the depth profile is reduced to the maximum depth profile desired.

In accordance with the principles of the invention, it should be clearly understood, however, that to maintain the apparent integrity of two-dimensional image 115 when texture-mapping the image onto the segmented sections, each segmented sections 205₁₋₄, 205'₁₋₄, 210₁₋₄, and 210'₁₋₄ is scaled accordingly with respect to the user's current viewpoint, V, so as to appear to be of the same size as the original corresponding section. This scaling or transform is given by:

$$S_t = S_p \frac{T_t}{T_p}$$

where S_p is the size of the original pyramidal section; S_t is the size of the translated, segmented pyramidal panel section; T_p is distance to the original pyramidal section from the user's viewpoint, V; and T_t is the distance to the translated, segmented pyramidal section. In other words, each segmented, translated section is scaled by the ratio T_t/T_p. Of course, as the user moves within the world, pyramidal panels 145₁₋₄ are accordingly re-segmented, translated, and then scaled with respect to the user's new viewpoint, V. Then, the

images in original panels 145₁₋₄ are again accordingly texture-mapped into the corresponding translated sections 205₁₋₄, 205'₁₋₄, 210₁₋₄, and 210'₁₋₄ of the pyramidal panel structure.

The foregoing merely illustrates the principles of the invention. It will thus be appreciated that those skilled in the art will be able to devise various arrangements which, although not explicitly described or shown herein, embody the principles of the invention and are included within its spirit and scope.

What is claimed is:

1. A method for use in processing a view of a three-dimensional world in which a first portion of said world is modeled as computer graphics and a second portion of said world is represented by a two-dimensional image texture-mapped on a panel, comprising the steps of:

determining the current viewpoint of the user, V;
dividing the panel into triangular regions;

distorting the triangular regions to form pyramidal panels such that a corresponding vanishing point, P, of a portion of the two-dimensional image moves as a function of the current viewpoint of the user;

segmenting each of said pyramidal panels into a plurality of sections;

translating each of said plurality of sections of said pyramidal panels towards, or away from, said current viewpoint of the user, V;

texture-mapping the two-dimensional image onto the plurality of sections of the pyramidal panels; and
as the user moves within the three-dimensional world, repeating the above steps so as to limit discontinuities between the two-dimensional image and the computer graphics.

2. The invention as defined in claim 1 wherein said segmenting step includes resegmenting said pyramidal panels into a greater number of smaller sections until the depth profile of the pyramidal panel structure formed from said panels reaches a predetermined level.

3. The invention as defined in claim 1 wherein an outer edge of each of said plurality of sections of said pyramidal panels is located on the surface of a predetermined plane.

4. The invention as defined in claim 3 wherein said predetermined plane is the panel onto which the two-dimensional image texture-mapped.

5. The invention as defined in claim 1 wherein the center of each of said plurality of sections of said pyramidal panels is substantially located at the surface of a predetermined plane.

6. The invention as defined in claims 5 wherein said predetermined plane is the panel onto which the two-dimensional image is texture-mapped.

7. The invention as defined in claim 1 further comprising scaling each of said plurality of sections of said pyramidal panels in accordance with the following relationship

$$S_t = S_p \frac{T_t}{T_p}$$

where S_p is the size of the section; S_t is the size of the translated section; T_p is distance the section from the user's viewpoint, V; and T_t is the distance to the translated section from the user's viewpoint, V.

8. The invention as defined in claim 1 further comprising determining a vector, C, corresponding to the direction of a portion of a path contained within the two-dimensional

perspective image, and projecting toward the panel the vector, \bar{C} , from the image's ideal viewing point, IVP, the intersection of said vector, \bar{C} , with the panel being denoted as the image's vanishing point, P.

9. The invention as defined in claim 1 wherein said distorting of the triangular regions in said distorting step includes determining a new vanishing point, P', for said two-dimensional image in accordance with the following relationship $P'=P+\bar{T}$, wherein \bar{T} is a vector from the image's ideal viewing point, IVP, to the current viewpoint, V.

10. The invention as defined in claim 1 further comprising the step of calibrating the two-dimensional perspective image as a function of the dimensions of the surroundings within the world.

11. The invention as defined in claim 1 wherein said two-dimensional perspective image is a frame of a video.

12. The invention as defined in claim 1 wherein said two-dimensional perspective image is a still picture.

13. A method for use in processing a view of a three-dimensional world in which a first portion of said world is modeled as computer graphics and a second portion of said world is represented by a two-dimensional image texture-mapped on a panel, said two-dimensional image including an object depicted in perspective, said image being such that features of the object closer to a predetermined point of the image are farther away from a user's viewpoint, comprising the steps of:

determining a vector, \bar{C} , corresponding to the direction of said perspective object in the three-dimensional world; projecting towards said panel the vector, \bar{C} , from the

two-dimensional image's ideal viewing point, IVP, the intersection of said vector, \bar{C} , with the panel being denoted as the image's vanishing point, P;

segmenting said panel into triangular regions intersecting at the image's vanishing point, P;

determining the current viewpoint, V, of the user and projecting a vector, \bar{T} , from the image's ideal viewing point, IVP, to the current viewpoint, V;

determining a new vanishing point for the two-dimensional image in accordance with the following relationship $P'=P+\bar{T}$;

distorting the triangular regions in the space of the three-dimensional world such that they intersect at the new vanishing point, P';

segmenting each of said triangular regions into a plurality of sections;

translating each of said plurality of sections of said triangular regions towards, or away from, said current viewpoint of the user, V; and

texture-mapping the two-dimensional image in the triangular regions onto the corresponding sections of said triangular regions.

14. The invention as defined in claim 13 wherein said segmenting step of said triangular regions includes resegmenting said triangular regions into a greater number of smaller sections until the depth profile of the pyramidal panel structure formed from said triangular regions reaches a predetermined level.

15. The invention as defined in claim 13 wherein said predetermined point is substantially near the center of the two-dimensional image.

16. The invention as defined in claim 13 further comprising displaying the texture-mapped two-dimensional image merged with the first portion of said world that is modeled as computer graphics.

17. The invention as defined in claim 13 further comprising the step of calibrating the two-dimensional image as a function of the dimensions of the surroundings within the world.

18. The invention as defined in claim 13 wherein an outer edge of each of said plurality of sections of said triangular regions is located on the surface of a predetermined plane.

19. The invention as defined in claims 18 wherein said predetermined plane is the panel onto which the two-dimensional image is texture-mapped.

20. The invention as defined in claim 13 wherein the center of each of said plurality of sections of said triangular regions is located on the surface of a predetermined plane.

21. The invention as defined in claim 20 wherein said predetermined plane is the panel onto which the two-dimensional image is texture-mapped.

22. The invention as defined in claim 13 further comprising scaling each of said plurality of sections of said triangular regions in accordance with the following relationship

$$S_t = S_p \frac{T_t}{T_p},$$

20 where S_p is the size of the section; S_t is the size of the translated section; T_p is distance to the section from the user's viewpoint, V; and T_t is the distance to the translated section from the user's viewpoint, V.

23. An apparatus for use in processing a view of a three-dimensional world in which a first portion of said world is modeled as computer graphics and a second portion of said world is represented by a two-dimensional perspective image, said apparatus comprising:

means for determining the current viewpoint of the user, V;

means for dividing the panel into triangular regions; as the user moves within the three-dimensional world,

means for dynamically distorting the triangular regions to form pyramidal panels such that a corresponding vanishing point, P, of a portion of the two-dimensional image moves as a function of the current viewpoint of the user;

means for segmenting each of said pyramidal panels into a plurality of sections;

means for translating each of said plurality of sections of said pyramidal panels towards, or away from, said current viewpoint of the user, V; and

means for texture-mapping the two-dimensional image onto the plurality of sections of the pyramidal panels.

24. The invention as defined in claim 23 wherein an outer edge of each of said plurality of sections of said pyramidal panels is located on the surface of a predetermined plane.

25. The invention as defined in claim 24 wherein said predetermined plane is the panel onto which the two-dimensional image is texture-mapped.

26. The invention as defined in claim 23 wherein the center of each of said plurality of sections of said pyramidal panels is located on the surface of a predetermined plane.

27. The invention as defined in claim 23 further comprising means for scaling each of said plurality of sections of said pyramidal panels in accordance with the following relationship

$$S_t = S_p \frac{T_t}{T_p},$$

60 where S_p is the size of the section; S_t is the size of the translated section; T_p is distance to the original section from the user's viewpoint, V; and T_t is the distance to the translated section from the user's viewpoint, V.

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28. The invention as defined in claim 23 further comprising means for determining a vector, \vec{C} , corresponding to the direction of a portion of a path contained within the two-dimensional perspective image, and means for projecting toward the panel the vector, \vec{C} , from the image's ideal viewing point, IVP, the intersection of said vector, \vec{C} , with the panel being denoted as the image's vanishing point, P.

29. The invention as defined in claim 23 wherein said means for distorting the triangular regions includes means for determining a new vanishing point, P' , for said two-dimensional image in accordance with the following rela-

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tionship $P' = P + \vec{T}$, wherein \vec{T} is a vector from the image's ideal viewing point, IVP, to the current viewpoint, V.

30. The invention as defined in claim 23 further comprising means for calibrating the two-dimensional perspective image as a function of the dimensions of the surroundings within the world.

31. The invention as defined in claim 23 wherein said two-dimensional perspective image is a frame of a video.

32. The invention as defined in claim 23 wherein said two-dimensional perspective image is a still picture.

* * * * *



US006229548B1

(12) **United States Patent**
Edmark

(10) Patent No.: **US 6,229,548 B1**
(45) Date of Patent: **May 8, 2001**

(54) **DISTORTING A TWO-DIMENSIONAL IMAGE TO REPRESENT A REALISTIC THREE-DIMENSIONAL VIRTUAL REALITY**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/107,059**

(22) Filed: **Jun. 30, 1998**

(51) Int. Cl.⁷ **G06T 17/00**

(52) U.S. Cl. **345/427**

(58) Field of Search **345/427, 433, 345/139, 473, 418, 419, 474**

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(57) **ABSTRACT**

A limitation of using two-dimensional images, such as videos or photographs, to represent portions of a three-dimensional world occurs when the user moves within the world and views the world from a location different than from the original context of the two-dimensional image, i.e., from a location different than the image's ideal viewing point (IVP). View changes result in the image not aligning well with the surrounding objects of the three-dimensional world. This limitation is overcome by distorting the two-dimensional image so as to adjust the image's vanishing point(s) in accordance with the movement of the user. In this manner, as the user moves away from the ideal viewing point, the distortions act to limit the discontinuities between the two-dimensional image and its surroundings.

44 Claims, 8 Drawing Sheets

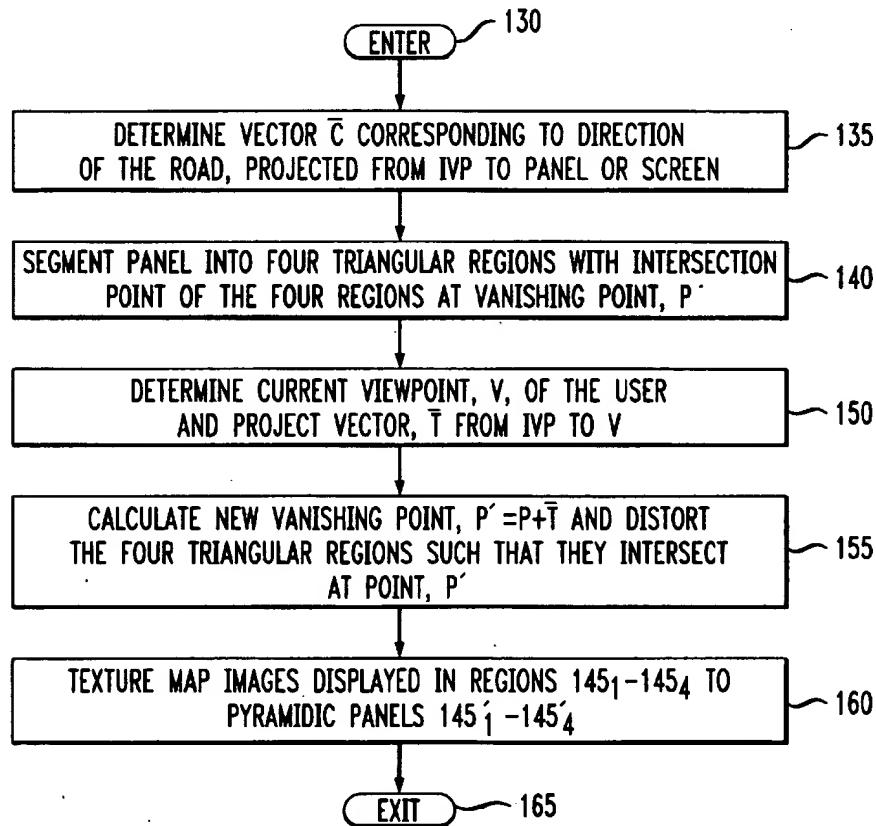


FIG. 1

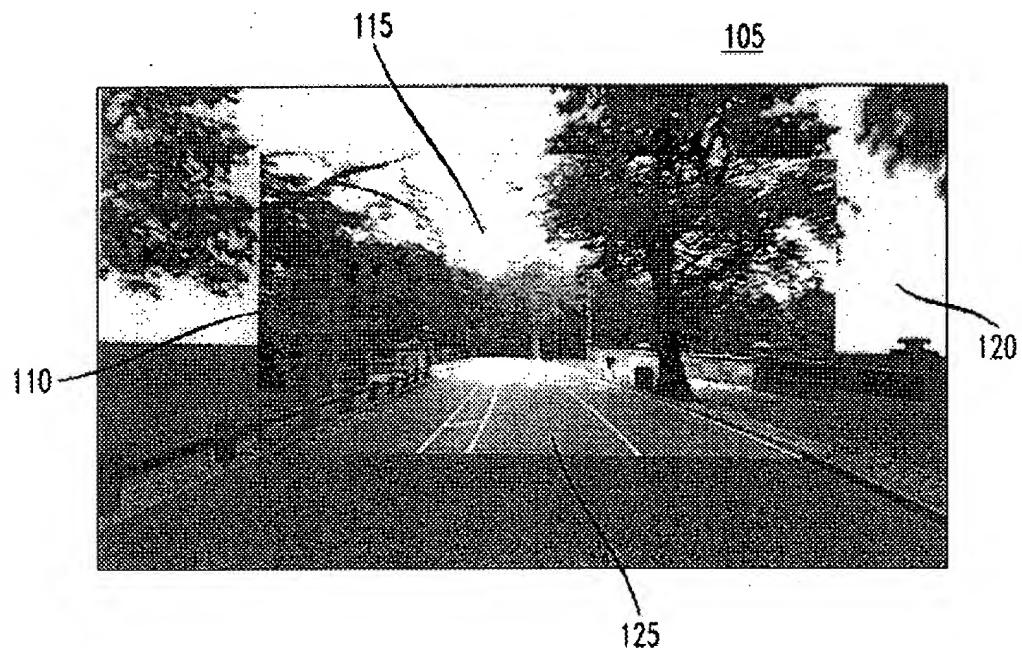


FIG. 2

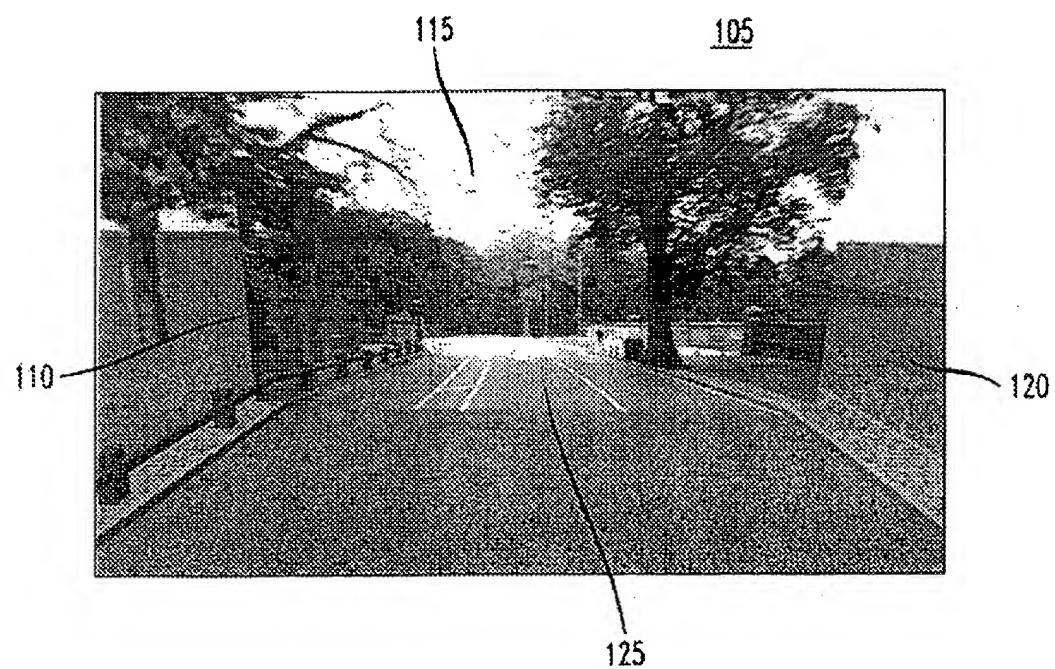


FIG. 3

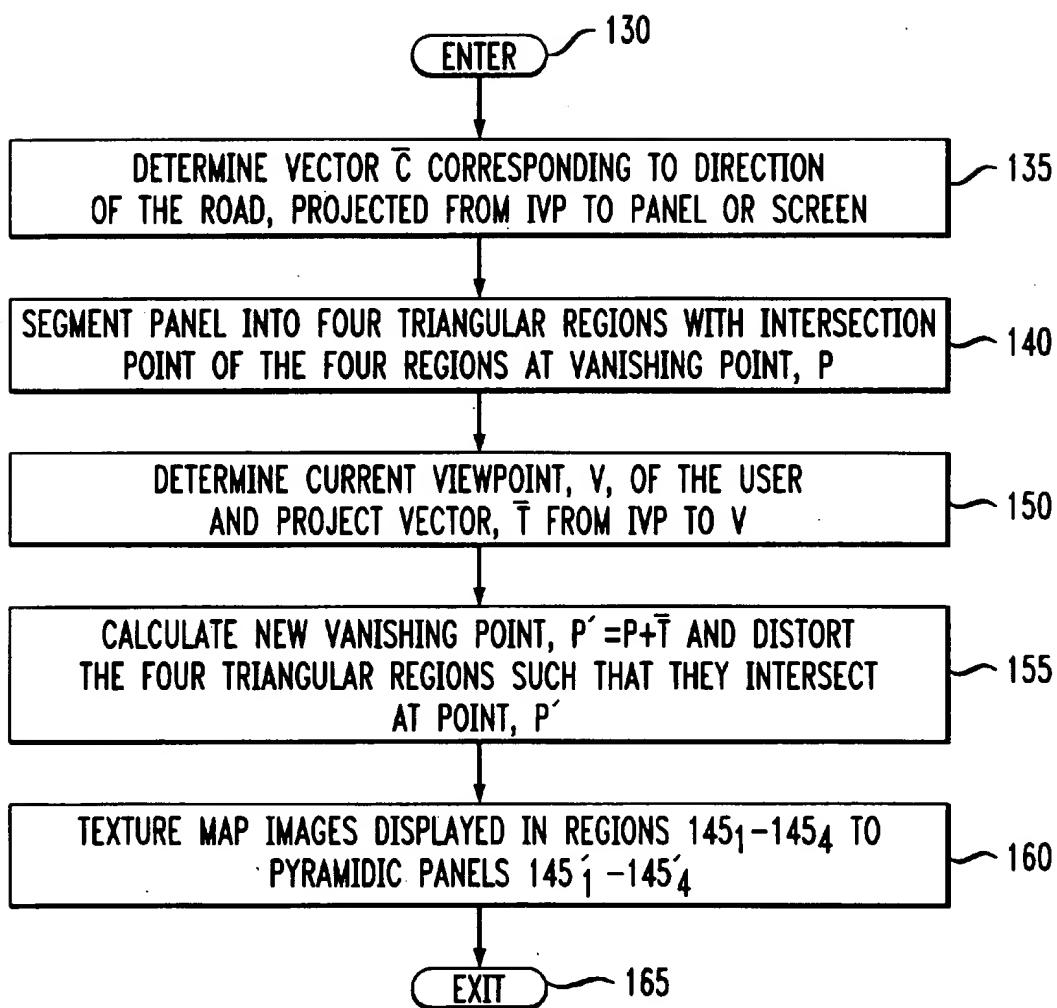


FIG. 4

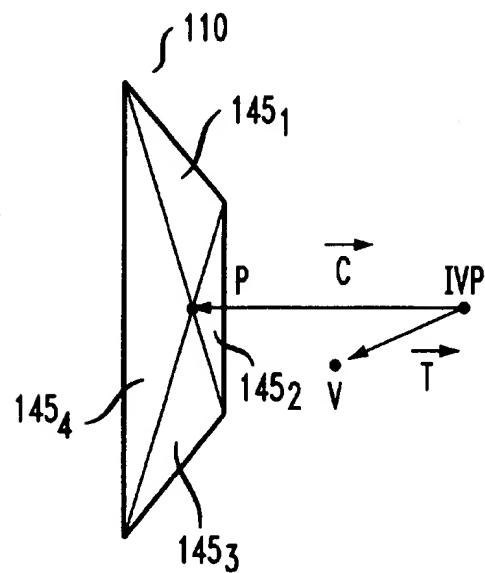


FIG. 5

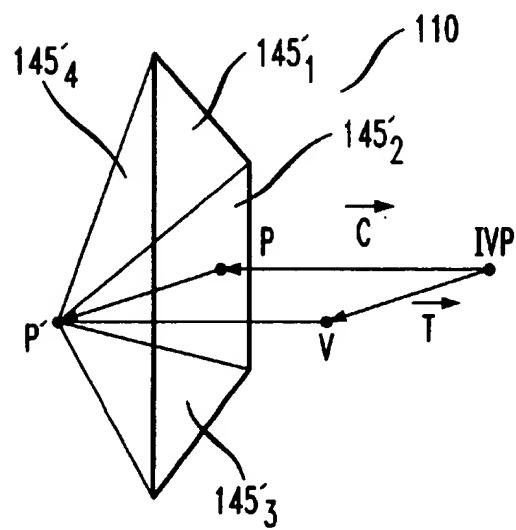


FIG. 6A

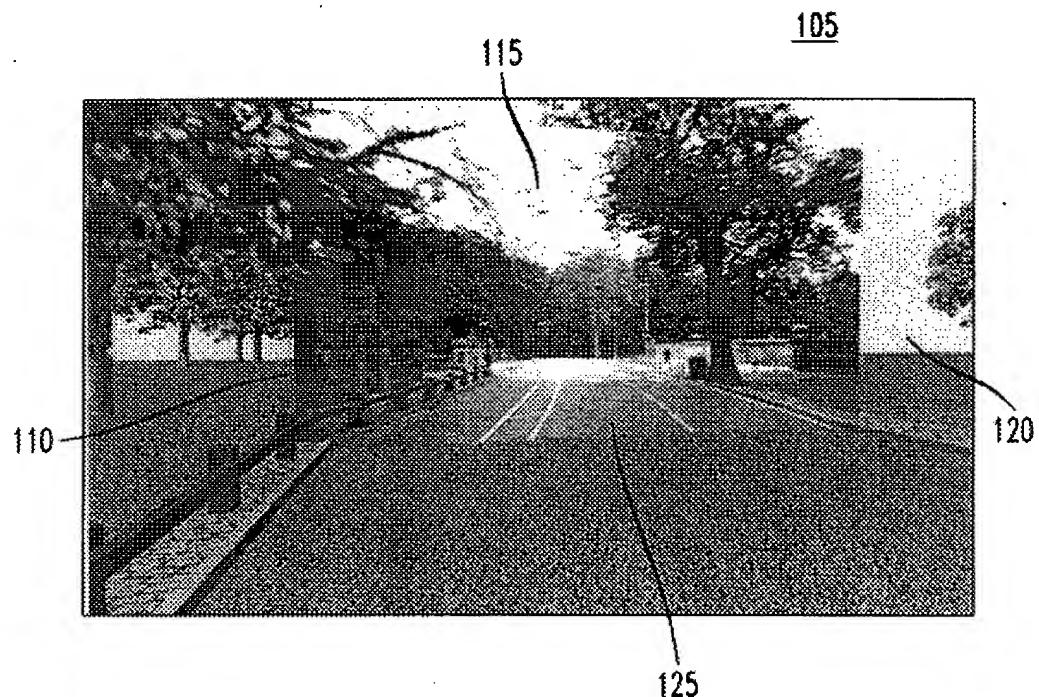


FIG. 6B

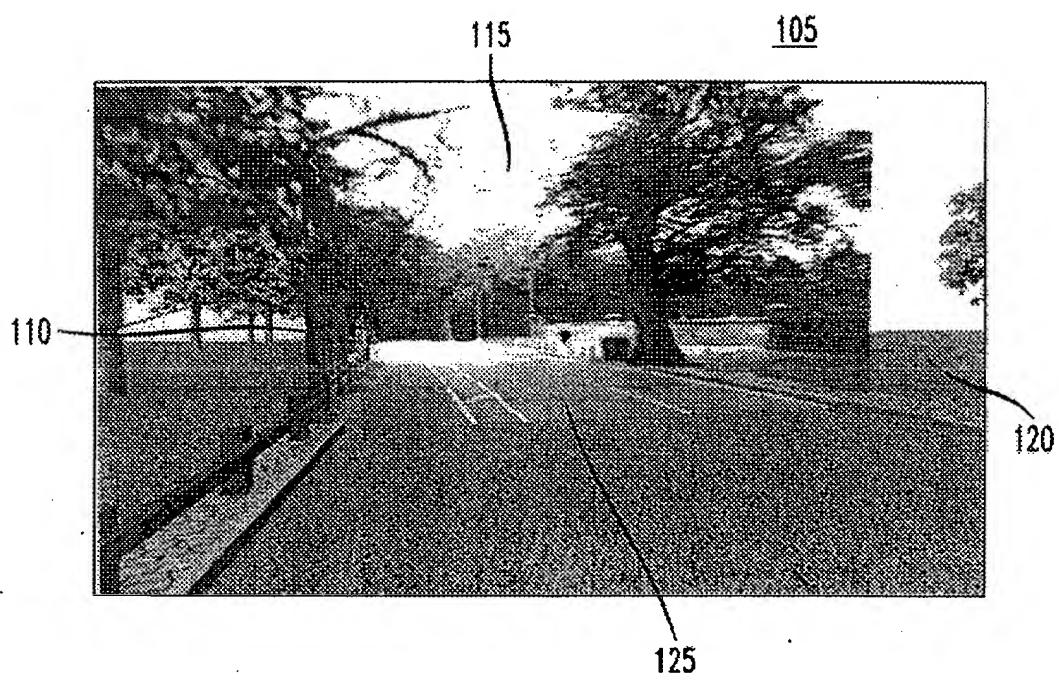


FIG. 7A

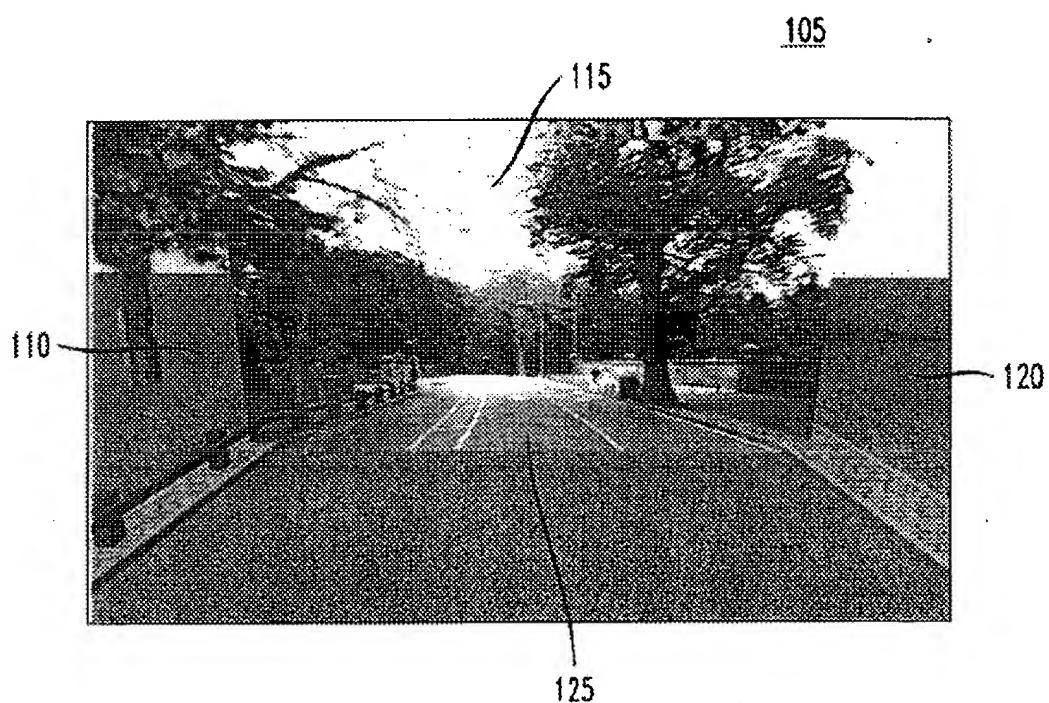


FIG. 7B

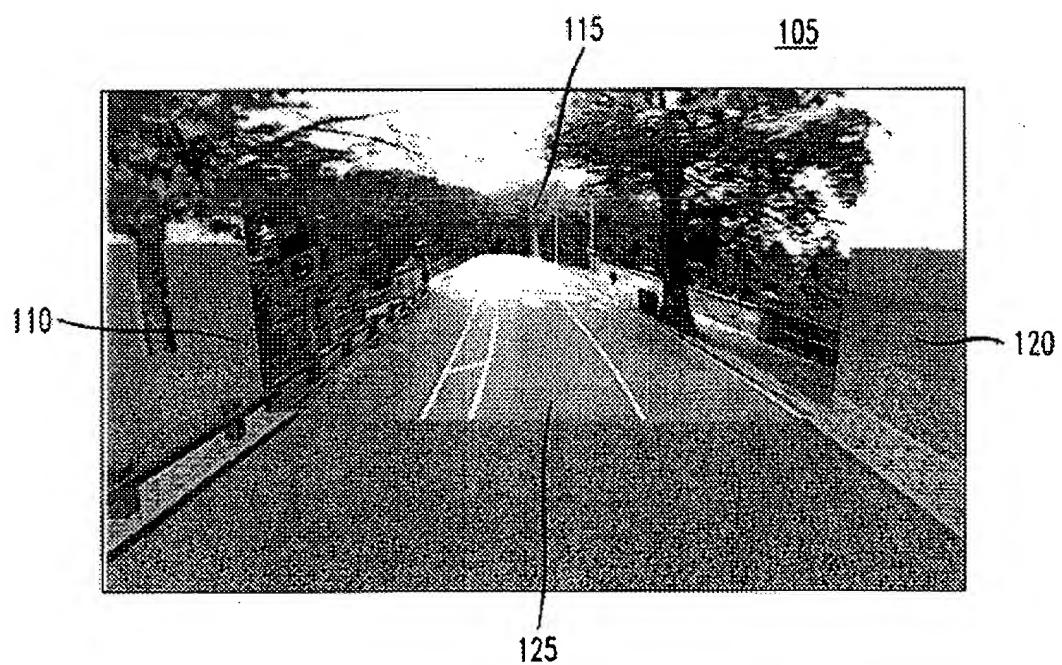


FIG. 8A

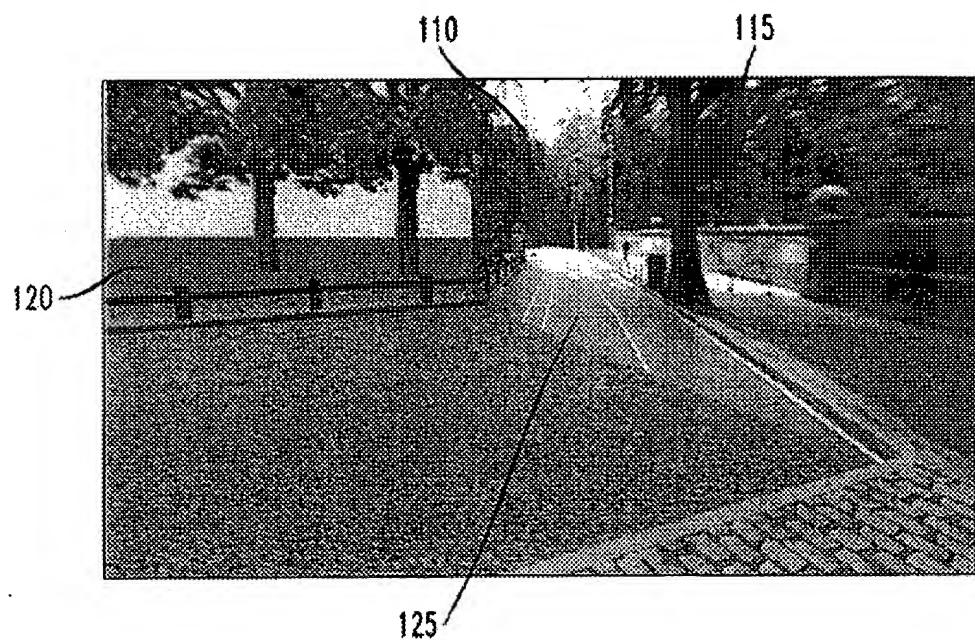
105

FIG. 8B

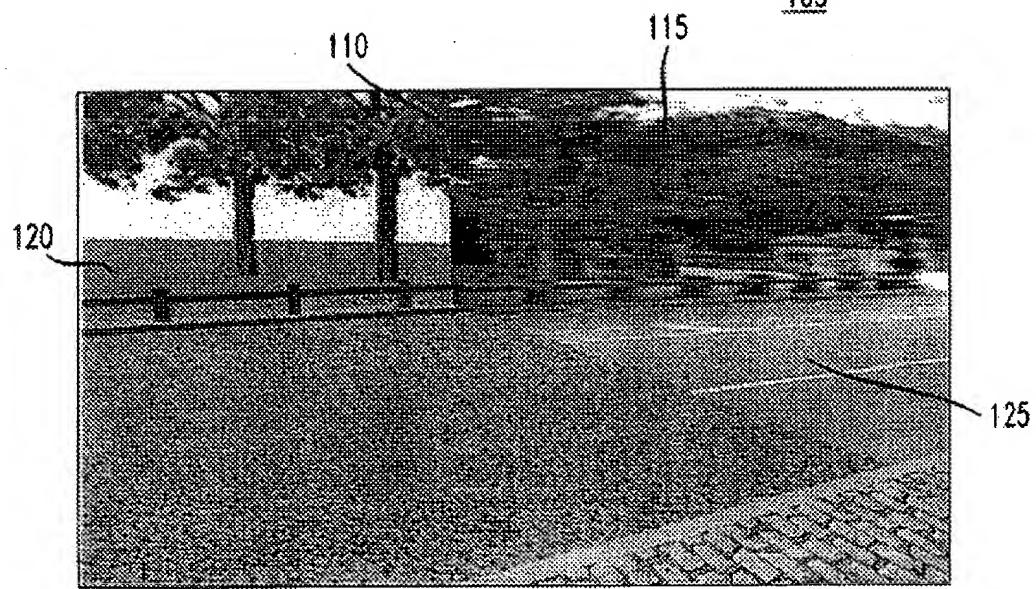
105

FIG. 9

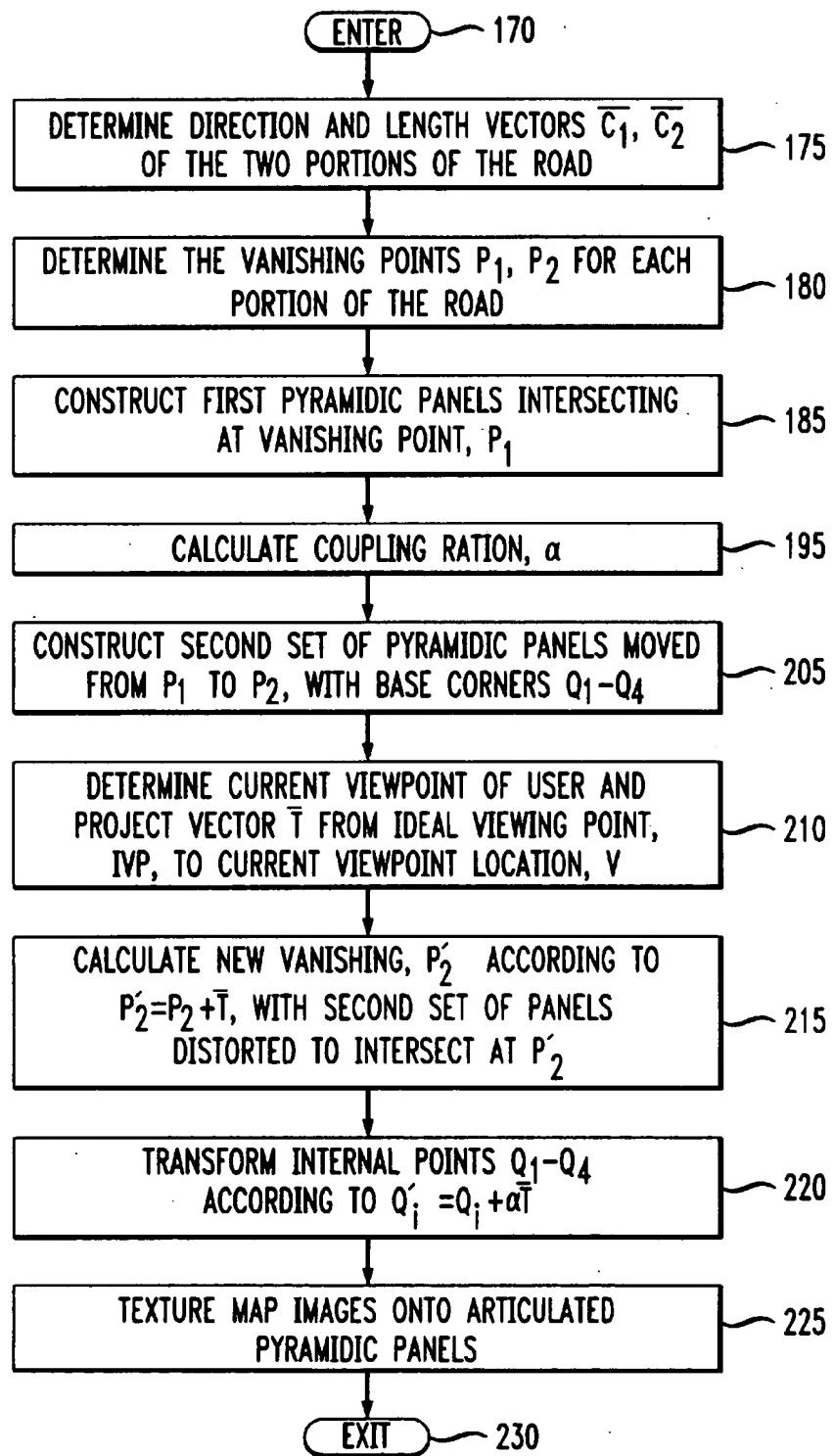


FIG. 10

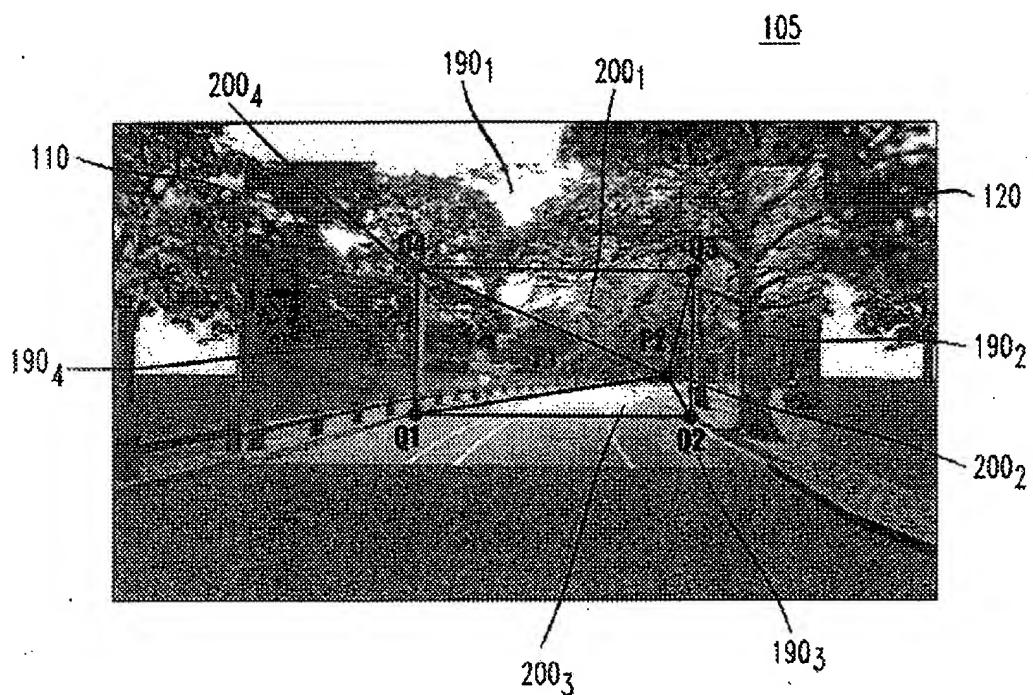
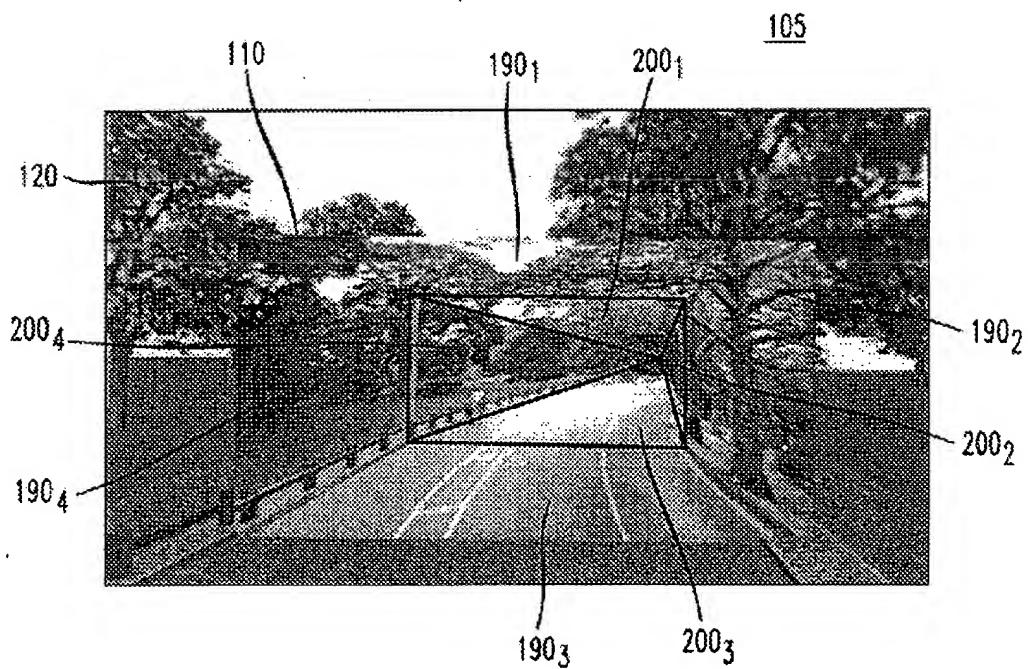


FIG. 11



DISTORTING A TWO-DIMENSIONAL IMAGE TO REPRESENT A REALISTIC THREE-DIMENSIONAL VIRTUAL REALITY

TECHNICAL FIELD

This invention relates to the integration of three-dimensional computer graphics and a two-dimensional image to provide a realistic three-dimensional virtual reality experience.

BACKGROUND OF THE INVENTION

The display of a three-dimensional virtual reality world to a user requires considerable computation power, and it is typically costly to develop the necessary highly detailed models required for doing so. In order to simplify the problem, two-dimensional images, such as videos or photographs, may be used to represent or simulate portions of the three-dimensional world. A great reduction in computation power and cost can be achieved by such an arrangement.

SUMMARY OF THE INVENTION

A limitation of such a world occurs when a user moves within the world and views the world from a location different than the original context of a two-dimensional image carefully calibrated to "fit into" the world. View changes, such as from a location different than the image's ideal viewing point, result in the image not aligning or fitting well with the surrounding objects of the three-dimensional world. We have recognized that, in accordance with the principles of the invention, viewpoint changes may be dealt with by distorting the two-dimensional image so as to adjust the image's vanishing point(s) in accordance with the movement of the user. In this manner, as the user moves away from the ideal viewing point, the distortions act to limit the discontinuities between the two-dimensional image and the surroundings of the world.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings:

FIG. 1 shows an example of that which a user sees when a user views the world from the ideal viewing point for a two-dimensional image representing a portion of the world;

FIG. 2 shows an example of that which a user sees when a user moves within the world of FIG. 1 and views the two-dimensional image from a location different than the image's ideal viewing point, without the use of the present invention;

FIG. 3 shows an exemplary process, in accordance with the principles of the invention, for distorting the two-dimensional image using a pyramidal panel structure so as to adjust the image's vanishing point in accordance with the movement of the user;

FIGS. 4 and 5 depict the pyramidal panel structure of the present invention for distorting the two-dimensional image so as to adjust the image's vanishing point, in accordance with the movement of the user;

FIGS. 6A-B depict examples of that which a user sees when a user views the world from a location left of the image's ideal viewing point, without and with the use of the present invention, respectively;

FIGS. 7A-B depict examples of that which a user sees when a user views the world from a location above the image's ideal viewing point, without and with the use of the present invention, respectively;

FIGS. 8A-B depict examples of that which a user sees when a user views the world from a location toward the front and the right of the image's ideal viewing point, without and with the use of the present invention, respectively;

10 FIG. 9 shows an exemplary process, in accordance with the principles of the invention, for distorting a two-dimensional image using an articulated pyramidal panel structure so as to adjust multiple vanishing points in the image, in accordance with the movement of the user;

15 FIG. 10 depicts an example of the articulated pyramidal panel structure of the present invention; and

20 FIG. 11 depicts an example of that which a user sees when a user views the world from a location away from the ideal viewing point of the two-dimensional image, with the use of the articulated pyramidal panel structure of the present invention.

DETAILED DESCRIPTION

25 To better understand the invention, FIGS. 1-2 show examples of that which a user sees when the user moves within a three-dimensional virtual reality world and views a two-dimensional image representing a portion of the world from a location at the image's ideal viewing point (IVP), and then from a different location, i.e., a location different than the original context of the image. It should be understood that the two-dimensional image has been carefully calibrated to "fit into" the surroundings of the world. For simplification of terminology purposes, we shall use the term "two-dimensional image" to denote either a video clip or a photograph. In accordance with the principles of the invention, as the user moves away from the ideal viewing point, discontinuities between the two-dimensional image and its surroundings are minimized by distorting the image according to the movement of the user.

30 FIG. 1 shows an exemplary three-dimensional reality world 105, which is a bicycle path in a park, e.g., Central Park in New York City. In representing world 105, the present invention exploits a characteristic common to images consisting of views looking down the center of roads, streets or paths, which is that they may be treated as perspective, corridor-like images, with features closer to the center of the image being farther away from the viewer. Accordingly, the bicycle path or road and its immediate vicinity are treated as a kind of three-dimensional, corridor-like image whose floor is formed by the roadbed, whose ceiling is formed by the sky, and whose sidewalls are formed by the roadside objects. In this manner, the principles of a simple point perspective can be used for distorting the landscape image in accordance with the movement of the viewer, as discussed hereinbelow.

35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110 115 120 125 130 135 140 145 150 155 160 165 170 175 180 185 190 195 200 205 210 215 220 225 230 235 240 245 250 255 260 265 270 275 280 285 290 295 300 305 310 315 320 325 330 335 340 345 350 355 360 365 370 375 380 385 390 395 400 405 410 415 420 425 430 435 440 445 450 455 460 465 470 475 480 485 490 495 500 505 510 515 520 525 530 535 540 545 550 555 560 565 570 575 580 585 590 595 600 605 610 615 620 625 630 635 640 645 650 655 660 665 670 675 680 685 690 695 700 705 710 715 720 725 730 735 740 745 750 755 760 765 770 775 780 785 790 795 800 805 810 815 820 825 830 835 840 845 850 855 860 865 870 875 880 885 890 895 900 905 910 915 920 925 930 935 940 945 950 955 960 965 970 975 980 985 990 995 1000 1005 1010 1015 1020 1025 1030 1035 1040 1045 1050 1055 1060 1065 1070 1075 1080 1085 1090 1095 1100 1105 1110 1115 1120 1125 1130 1135 1140 1145 1150 1155 1160 1165 1170 1175 1180 1185 1190 1195 1200 1205 1210 1215 1220 1225 1230 1235 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120. Within CG Part 120 there are various synthetic, three-dimensional landscapes or objects modeled in, for example, the Virtual Reality Modeling Language (VRML). Two-dimensional image 115 simulates landscape or terrain portions of the world 105, here a virtual road or course 125 for walking, running or pedaling a bicycle.

Note that although three-dimensional world 105 cannot be actually rendered in a two-dimensional plane, it can be projected to and displayed on a two-dimensional plane so as to appear to have three dimensions. Accordingly, the techniques of the present invention are preferably employed with computers and software, which are sufficiently sophisticated to display images on a two-dimensional plane as having three dimensions. Note also that to make the world look realistic, computer graphics display techniques use the z component of objects to scale accordingly the x and y components as a function of its distance to the user's viewpoint.

Two-dimensional image 115 is carefully placed, cropped and sized to achieve continuity with the surrounding environment of the CG Part 120. Note that the image is clipped so that the left and right edges of the road in CG Part 120 pass through the left and right bottom corners of the road, respectively, in image 115. This clipping ensures that the roadbed maps to the floor of the hypothetical corridor. In so doing, portions at the boundary between two-dimensional image 115 and CG part 120 are co-planar, i.e., at the same distance away from the user's viewpoint. In "fitting" two-dimensional image 115 to CG part 120, however, there exists only one viewpoint from which that image's content properly corresponds to the surrounding environment of CG Part 120. This unique location is called the image's ideal viewing point (IVP). In FIG. 1, two-dimensional image 115 is seen from its ideal viewing point, and from this view, image 115 aligns well with the surrounding objects of CG Part 120.

Users, however, rarely view image 115 only from its ideal viewing point. As the user moves within world 105, such as left or right of road 125, as they round curves, or move closer to or farther from the image, they see image 115 from positions other than its ideal viewing point. Absent the use of the present invention, such viewpoint changes would cause objects or features within image 115 to align improperly with the surrounding environment, as further illustrated in FIG. 2.

In accordance with the principles of the invention, however, screen or panel 110 uses a display structure called a "pyramidal panel structure" for displaying two-dimensional image 115 within the surrounding three-dimensional space of the CG Part 105 so as to deal with viewpoint changes. The transformations associated with the pyramidal panel structure dynamically distort two-dimensional image 115 according to viewer's position so as to adjust the image's vanishing point with the viewer's movement. As the viewer moves from the image's ideal viewing point, these distortions act to limit discontinuities between image 115 and the surroundings of CG Part 120.

FIG. 3 shows an exemplary process in accordance with the principles of the invention for distorting two-dimensional image 115 so as to adjust its vanishing point in accordance with the viewer's position. The process is entered at step 130 whenever it is determined that the viewer's position has changed.

Using the virtual world's road model of the CG Part 105, a vector, \vec{T} , corresponding to the direction of road 125 is projected at step 135 from the image's ideal viewing point, IVP, to panel or screen 110 on which is displayed image 115. Note that the panel is two-dimensional, but represents three-dimensional space with objects nearer the center of the image being farther away from the plane of the viewer. The panel structure is shown in FIG. 4. The point of intersection with screen or panel 110 is the image's vanishing point, P.

10 Note, however, that the vanishing point may be set visually by the user, if desired, or by other suitable computer graphics processing techniques known in the art. Next, in step 140, screen or panel 110 is segmented into four triangular regions 145₁₋₄, one for each of the regions bordering CG Part 120, with the intersection point of the four regions located at the vanishing point, P.

Thereafter in step 150, the current viewpoint of the user, V, is determined, and a vector \vec{T} projected from the ideal viewing point, IVP, to the viewer's current location, V. In accordance with the principles of the invention, as the viewer moves, a new vanishing point P' is calculated as P' = P + \vec{T} . The four triangular regions 145₁₋₄ are distorted in the three-dimensional space of the virtual world at step 155 to represent the mapping of objects nearer the center of the image being displaced farther away from the viewpoint of the user. The four triangular regions intersect at the new vanishing point P' and form so-called "pyramidal panels" 145'₁₋₄. This is illustrated in FIG. 5. At step 160, the corresponding images displayed in regions 145₁₋₄ are then "texture-mapped" onto pyramidal panels 145'₁₋₄, respectively. In this manner, as the viewer moves away from the image's ideal viewing point, IVP, distortions in the image resulting from moving the image's vanishing point from P to P' act to limit the discontinuities between image 115 and the surroundings within CG Part 105.

In the exemplary illustration of FIG. 5, distorting image 115 so as to move the vanishing point from P to P' results in pyramidal panel structure forming a four-sided pyramid. Note that its base is fixed and corresponds to original screen or panel 110, with its peak located at P', which moves in concert with the viewer's current location, V. As the user's viewpoint moves closer to and farther from the image, the image's vanishing point accordingly moves farther from and closer to the user's viewpoint, respectively.

FIGS. 6 through 8 compare the display of two-dimensional image 115 on screen or panel 110 with the display of the same image using the "pyramidal" panels of the present invention. More specifically, FIGS. 6A, 7A and 8A depict viewing two-dimensional image 115 at a location from the left, above, and in front and to the right of the image's ideal viewing point, IVP, respectively, without the use of the present invention. In these latter Figures, note that there are discontinuities between the edges of the road and the three-dimensional space of CG Part 105. FIGS. 6B, 7B and 8C depict the same two-dimensional image distorted and texture-mapped onto pyramidal panels 145'₁₋₄, in accordance with the principles of the invention. Note that in these latter figures, the discontinuities in the road edge have been substantially eliminated.

In another embodiment of the present invention, a modified pyramidal panel structure may be used to deal with

two-dimensional images containing curved roads, streets, paths and other corridor-like images containing multiple rather than a single vanishing point. In this latter case, screen or panel 110 is segmented using multiple vanishing points to form a so called "articulated pyramidal panel structure." The transformations associated with the articulated pyramidal panel structure dynamically distort different portions of two-dimensional image 115 according to viewer positions so as to adjust the different vanishing points of the image with the viewer's movement. Likewise, as the viewer moves from the image's ideal viewing point, these distortions act to limit the discontinuities between two-dimensional image 115 and the surroundings of CG Part 120.

FIG. 9 shows an exemplary process in accordance with the principles of the invention for distorting two-dimensional image 115 using an articulated pyramidal panel structure. Again, the process is entered at step 170 whenever it is determined that the viewer's position has changed. In general, curve road 125 is treated as two straight corridors placed end-to-end, extending back from screen or panel 110. Each corridor represents a different portion of road 125 in the three-dimensional space of world 105, with features nearer the center of the image being farther away from the user's viewpoint.

Using the virtual world's road model of the CG Part 105, corresponding directional vectors C_1 and C_2 of the corridors are determined at step 175. Note that portion of the road nearer to the user's viewpoint is represented by C_1 , and the portion farther away is represented by C_2 . Next, in step 180, using the vectors C_1 and C_2 , the corresponding vanishing points P_1 and P_2 are determined, respectively, for each corridor by projecting those vectors from the image's ideal viewing point, IVP. Alternatively, vanishing points P_1 and P_2 may be determined visually by the user, or by some other suitable means known in the art. In step 185, using the first corridor's vanishing point, P_1 , a first set of pyramidal panels 190₁₋₄ are constructed to intersect at vanishing point, P_1 , as shown in FIG. 10.

Now at step 195, a coupling ratio α is calculated according to the following equation: $\alpha=l(l+d)$, where l is the length of the first corridor, and d is the distance between the image's ideal view point (IVP) and the base of pyramidal panels 190₁₋₄. Each line segment connecting a corner of the base to vanishing point P_1 is then divided into two segments by a point placed according to the coupling ratio, α . More specifically, the length l' of each line segment from the corner of the base of panels 190₁₋₄ to this point is given by $l'=al'$, where l'' is the total length of the segment between the corner of the panel and the vanishing point, P_1 . These four points labeled Q1 through Q4 are connected to form the base of a second set of smaller pyramidal panels 200₁₋₄ embedded within the larger panels (step 205), as further illustrated in FIG. 10. The intersection point of pyramidal panels 200₁₋₄ is then moved from P_1 to vanishing point, P_2 .

For the articulated pyramidal panel structure, the current viewpoint of the user, V , is determined, and a vector T projected from the ideal viewing point, IVP, to the viewer's current location, V (step 210). As the viewer moves, a new vanishing point P'_2 is calculated as $P'_2=P_2+T$ at step 215, and panels 200₁₋₄ are then distorted so as to intersect at P'_2 . As the viewer moves, the four internal points Q1 through Q4 are

mapped with the viewer's movement to Q1' through Q4', respectively, in accordance with the following relationship: $Q'_i=Q_i+\alpha T$, at step 220. Note that doing so, accordingly distorts the first set of pyramidal panels 190₁₋₄. At step 225, the corresponding images in original panels are then texture-mapped into articulated pyramidal panels 190₁₋₄ and 200₁₋₄, which have been distorted in accordance with the movement of the viewer. Note that to unambiguously texture-map onto panels 190₁₋₄, these panels are each subdivided into two triangular subregions and then texture-mapped. Shown in FIG. 11 is image 115 seen from a location away from the image's ideal viewing point, using the articulated pyramidal panel structure of the present invention.

Note that the above articulated pyramidal panel structure may also use more than two sets of pyramidal panel structures. Instead of treating the curve road as two straight corridors, multiple corridors may be employed, each placed end-to-end and extending back from screen or panel 110. Likewise, each corridor represents a different portion of road 125 in the three-dimensional space of world 105, with features nearer the center of the image being farther away from the user's viewpoint. In such a case, each set of articulated pyramidal panels are formed reiterately using the above described procedure.

The foregoing merely illustrates the principles of the invention. It will thus be appreciated that those skilled in the art will be able to devise various arrangements which, although not explicitly described or shown herein, embody the principles of the invention and are included within its spirit and scope.

What is claimed is:

1. A method for use in processing a view of a three-dimensional world in which a first portion of said world is modeled as computer graphics and a second non-computer modeled portion of said world is represented by a two-dimensional perspective image, comprising the steps of:

determining the current user's viewpoint of the two-dimensional perspective image, said image being such that features closer to a predetermined point of the image are farther away from the user's viewpoint so as to give a portion of the two-dimensional perspective image a vanishing point;

distorting the two-dimensional perspective image so as to move the vanishing point of said portion of the two-dimensional perspective image according to the current user's viewpoint; and as the user moves within the three-dimensional world, repeating the above steps so as to limit discontinuities between the two-dimensional perspective image and the computer graphics.

2. A method for use in processing a view of a three-dimensional world in which a first portion of said world is modeled as computer graphics and a second non-computer modeled portion of said world is represented by a two-dimensional perspective image, comprising the steps of:

determining the current user's viewpoint of the two-dimensional perspective image, said image being such that features closer to a predetermined point of the image are farther away from the user's viewpoint so as to give a portion of the two-dimensional perspective image a vanishing point; and

distorting the portions of the two-dimensional perspective image so as to adjust the corresponding vanishing point

of each of said portion according to the current user's viewpoint.

3. The invention as defined in claim 1 further comprising displaying the distorted two-dimensional perspective image merged with the first portion of said world that is modeled as computer graphics.

4. The invention as defined in claim 1 wherein said two-dimensional perspective image is a frame of a video.

5. The invention as defined in claim 1 wherein said two-dimensional perspective image is a still picture.

6. The invention as defined in claim 1 further comprising the step of calibrating the two-dimensional perspective image as a function of the dimensions of the surroundings within the world.

7. A method for use in processing a view of a three-dimensional world in which a first portion of said world is modeled as computer graphics and a second non-computer modeled portion of said world is represented by a two-dimensional perspective image, comprising the steps of:

determining the current user's viewpoint of the two-dimensional perspective image, said image being such that features closer to a predetermined point of the image are farther away from the user's viewpoint so as to give different portions of the two-dimensional perspective image vanishing points;

distorting different portions of the two-dimensional perspective image so as to adjust the corresponding vanishing point of each of said portions according to the current user's viewpoints and

as the user moves within the three-dimensional world, repeating the above steps so as to limit discontinuities between the two-dimensional perspective image and the computer graphics.

8. The invention as defined in claim 7 wherein said predetermined point is substantially near the center of the two-dimensional image.

9. The invention as defined in claim 7 further comprising displaying the distorted two-dimensional perspective image merged with the first portion of said world that is modeled as computer graphics.

10. The invention as defined in claim 7 wherein said two-dimensional perspective image is a frame of a video.

11. The invention as defined in claim 7 wherein said two-dimensional image perspective is a still picture.

12. The invention as defined in claim 7 further comprising the step of calibrating the two-dimensional perspective image as a function of the dimensions of the surroundings within the world.

13. A method for use in processing a view of a three-dimensional world in which a first portion of said world is modeled as computer graphics and a second non-computer modeled portion of said world is represented by a two-dimensional image, comprising the step of:

distorting the two-dimensional image, in which features closer to a predetermined point of the image are farther away from a user's viewpoint, so as to adjust a corresponding vanishing point of a portion of said two-dimensional image as a function of the current viewpoint of a user, and as the user moves within the three-dimensional world, repeating the above step so as to limit discontinuities between the two-dimensional image and the computer graphics.

14. The invention as defined in claim 13 wherein said predetermined point is substantially near the center of the two-dimensional image.

15. A method for use in processing a view of a three-dimensional world in which a first portion of said world is modeled as computer graphics and a second non-computer modeled portion of said world is represented by a two-dimensional image texture-mapped on a panel, comprising the steps of:

determining the current viewpoint of the user, V;

dividing the panel into triangular regions;

distorting the triangular regions to form pyramidal panels such that a corresponding vanishing point, P, of a portion of the two-dimensional image moves as a function of the current viewpoint of the user;

texture-mapping the two-dimensional image onto the pyramidal panels; and as the user moves within the three-dimensional world, repeating the above steps so as to limit discontinuities between the two-dimensional image and the computer graphics.

16. The invention as defined in claim 15 further comprising determining a vector, \bar{C} , corresponding to the direction of a portion of a path contained within the two-dimensional perspective image, and projecting toward the panel the vector, \bar{C} , from the image's ideal viewing point, IVP, the intersection of said vector, \bar{C} , with the panel being denoted as the image's vanishing point, P.

17. The invention as defined in claim 15 wherein said distorting of the triangular regions in said distorting step includes determining a new vanishing point, P' , for said two-dimensional image in accordance with the following relationship $P' = P + \bar{T}$, wherein \bar{T} is a vector from the image's ideal viewing point, IVP, to the current viewpoint, V.

18. The invention as defined in claim 15 further comprising the step of calibrating the two-dimensional perspective image as a function of the dimensions of the surroundings within the world.

19. A method for use in processing a view of a three-dimensional world in which a first portion of said world is modeled as computer graphics and a second non-computer modeled portion of said world is represented by a two-dimensional image texture-mapped on a panel comprising the steps of:

determining the current viewpoint of the user;

dividing the panel into different regions corresponding to different portions of the two-dimensional image, said image being such that features closer to a predetermined point of the image are farther away from the user's viewpoint so as to give different portions of the two-dimensional image different vanishing points;

distorting the different regions of the panel to form articulated pyramidal panels such that the corresponding vanishing points of different portions of the two-dimensional image move as a function of the current viewpoint of the user;

texture-mapping the two-dimensional image onto the articulated pyramidal panels; and

as the user moves within the three-dimensional world, repeating the above step so as to limit discontinuities between the two-dimensional image and the computer graphics.

20. The invention as defined in claim 19 wherein said predetermined point is substantially near the center of the two-dimensional image.

21. The invention as defined in claim 19 wherein said two-dimensional perspective image is a frame of a video.

22. The invention as defined in claim 19 wherein said two-dimensional perspective image is a still picture.

23. The invention as defined in claim 19 further comprising the step of calibrating the two-dimensional perspective image as a function of the dimensions of the surroundings within the world.

24. The invention as defined in claim 19 wherein said first and second portions of the two-dimensional image include portions of a road with dissimilar directions.

25. A method for use in processing a view of a three-dimensional world in which a first portion of said world is modeled as computer graphics and a second non-computer modeled portion of said world is represented by a two-dimensional image texture-mapped on a panel, said two-dimensional image including an object depicted in perspective, said image being such that features of the object closer to a predetermined point of the image are farther away from a user's viewpoint, comprising the steps of:

determining a vector, \bar{C} , corresponding to the direction of said perspective object in the three-dimensional world; projecting towards said panel the vector, \bar{C} , from the two-dimensional image's ideal viewing point, IVP, the intersection of said vector, \bar{C} , with the panel being denoted as the image's vanishing point, P ;

segmenting said panel into triangular regions intersecting at the image's vanishing point, P ;

determining the current viewpoint, V , of the user and projecting a vector, \bar{T} , from the image's ideal viewing point, IVP, to the current viewpoint, V ;

determining a new vanishing point for the two-dimensional image in accordance with the following relationship $P' = P + \bar{T}$;

distorting the triangular regions in the space of the three-dimensional world such that they intersect at the new vanishing point, P' and

texture-mapping the two-dimensional image in the triangular regions onto said distorted triangular regions.

26. The invention as defined in claim 25 wherein said predetermined point is substantially near the center of the two-dimensional image.

27. The invention as defined in claim 25 further comprising displaying the texture-mapped two-dimensional image merged with the first portion of said world that is modeled as computer graphics.

28. The invention as defined in claim 25 further comprising the step of calibrating the two-dimensional image as a function of the dimensions of the surroundings within the world.

29. A method for use in processing a view of a three-dimensional world in which a first portion of said world is modeled as computer graphics and a second non-computer modeled portion of said world is represented by a two-dimensional image texture-mapped on a panel, said two-dimensional image including a path depicted in perspective wherein features of the path closer to a predetermined point of the image are farther away from a user's viewpoint, comprising the steps of:

dividing said path into first and second portions; determining vectors \bar{C}_1 and \bar{C}_2 corresponding to the direction and length of said first and second portions, respectively;

projecting towards said panel the vectors \bar{C}_1 and \bar{C}_2 from the two-dimensional image's ideal viewing point, IVP, the intersection of said vectors \bar{C}_1 and \bar{C}_2 with the panel being denoted as the image's vanishing points, P_1 and P_2 , respectively;

segmenting said panel into a first set of four triangular regions intersecting at the image's vanishing point, P_1 ; determining a coupling ratio α given by $\alpha = l/(l+d)$, where l is the length of the vector \bar{C}_1 , and d is the distance between the image's ideal viewing point, IVP, and the panel;

dividing each of the four line segments of the first set of four triangular regions connecting to a corner of the panel and labeling those points Q1 through Q4 with the exterior forming a first set of articulated pyramidal panels;

segmenting the regions interior to the points Q1 through Q4 into a second set of four triangular regions intersecting at vanishing point P_2 ;

moving the intersection point of the first set of the four triangular regions from P_1 to P_2 ;

determining the current viewpoint, V , of the user and projecting a vector, \bar{T} , from the image's ideal viewing point, IVP, to the current viewpoint, V ;

determining a new vanishing point for the second portion of the two-dimensional image in accordance with the following relationships,

$$P'_2 = P_2 + \bar{T};$$

distorting the second set of four triangular regions in the three-dimensional space of the world such that they intersect at the new vanishing point, P'_2 thereby forming a second set of articulated pyramidal panels;

mapping the points Q1 through Q4 to Q1' through Q4', respectively, according with the following relationship, $Q'_{i+Q_i} + \alpha \bar{T}$, where i an integer between 1 through 4; and

texture-mapping the corresponding first and second portions of the two-dimensional image in the first and second sets of triangular regions onto the first and second sets of articulated pyramidal panels, respectively.

30. The invention as defined in claim 29 wherein said predetermined point is substantially near the center of the two-dimensional image.

31. The invention as defined in claim 29 further comprising displaying the texture-mapped two-dimensional image merged with the first portion of said world that is modeled as computer graphics.

32. The invention as defined in claim 29 further comprising the step of calibrating the two-dimensional image as a function of the dimensions of the surroundings within the world.

33. An apparatus for use in processing a view of a three-dimensional world in which a first portion of said world is modeled as computer graphics and a second non-computer modeled portion of said world is represented by a two-dimensional perspective image, said apparatus comprising:

means for determining the current user's viewpoint of the two-dimensional perspective image, said perspective image being such that features of a perspective object closer to a predetermined point of the image are farther away from a user's viewpoint so as to give the perspective object a vanishing point; and

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as the user moves within the three-dimensional world, means for repeatedly distorting the two-dimensional perspective image so as to adjust the corresponding vanishing point of the perspective object within said image according to the current user's view point. 5

34. The invention as defined in claim 33 wherein said predetermined point is substantially near the center of the two-dimensional image.

35. The invention as defined in claim 33 further comprising means for displaying the distorted two-dimensional perspective image with the first portion of said world that is modeled as computer graphics. 10

36. The invention as defined in claim 33 wherein said two-dimensional perspective image is a frame of video. 15

37. The invention as defined in claim 33 wherein said two-dimensional perspective image is still a picture.

38. The invention as defined in claim 33 further comprising means for calibrating the two-dimensional perspective image as a function of the dimensions of the surroundings within the world. 20

39. An apparatus for use in processing a view of a three-dimensional world in which a first portion of said world is modeled as computer graphics and a second non-computer modeled portion of said world is represented by a two-dimensional perspective image, said apparatus comprising;

means for determining the user's current viewpoint of the two-dimensional perspective image, said two-

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dimensional perspective image being such that features closer to a predetermined point of the image are farther away from a user's viewpoint so as to give different portions of the two-dimensional perspective image each a vanishing point; and

as the user moves within the three dimensional world, means for repeatedly distorting portions of the two-dimensional perspective image so as to adjust the corresponding vanishing points of different portions of the two-dimensional image according to the current user's viewpoint.

40. The invention as defined in claim 39 wherein said predetermined point is substantially near the center of the two-dimensional image.

41. The invention as defined in claim 39 further comprising means for displaying the distorted two-dimensional perspective image merged with the first portion of said world that is modeled as computer graphics.

42. The invention as defined in claim 39 wherein said two-dimensional perspective image is a frame of a video.

43. The invention as defined in claim 39 wherein said two-dimensional perspective image is a still picture.

44. The invention as defined in claim 39 further comprising means for calibrating the two-dimensional perspective image as a function of the dimensions of the surroundings within the world. 25

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US 20020180733A1

(19) **United States**

(12) **Patent Application Publication**

Colmenarez et al.

(10) **Pub. No.: US 2002/0180733 A1**

(43) **Pub. Date: Dec. 5, 2002**

(54) **METHOD AND APPARATUS FOR
ADJUSTING AN IMAGE TO COMPENSATE
FOR AN OFFSET POSITION OF A USER**

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(21) **Appl. No.:** 09/858,211

(22) **Filed:** May 15, 2001

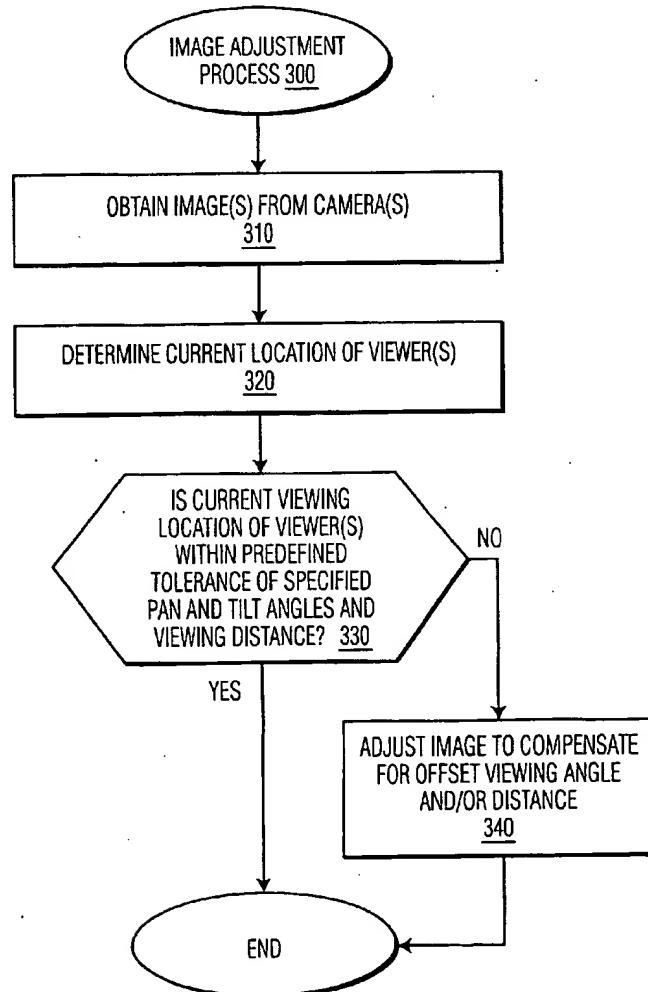
Publication Classification

(51) **Int. Cl. 7** G06T 15/10; G06T 15/20;
G09G 5/00

(52) **U.S. Cl.** 345/427; 345/660; 345/649

(57) **ABSTRACT**

A method and apparatus are disclosed for monitoring the location of one or more viewer(s) and dynamically adjusting the image to compensate for the current location of the viewer(s). The image is adjusted to compensate for a viewing location (pan angle, Θ , tilt angle, Φ , or distance, d) outside of a specified range of values. The input image is adjusted so that the output image appears as originally intended, for the current viewing location of the viewer. A linear transformation technique is applied to the original image to generate a modified image. The linear transformation maps the pixels in the original image to a new space that distorts the image, such that when the modified image is viewed from an offset viewing location the image appears as if being viewed from a direct viewing location.



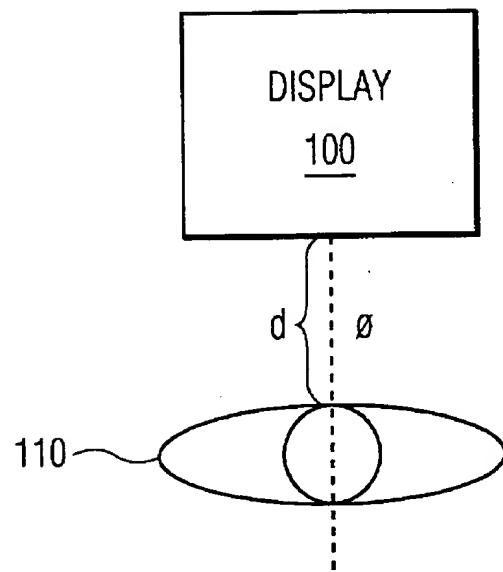


FIG. 1A

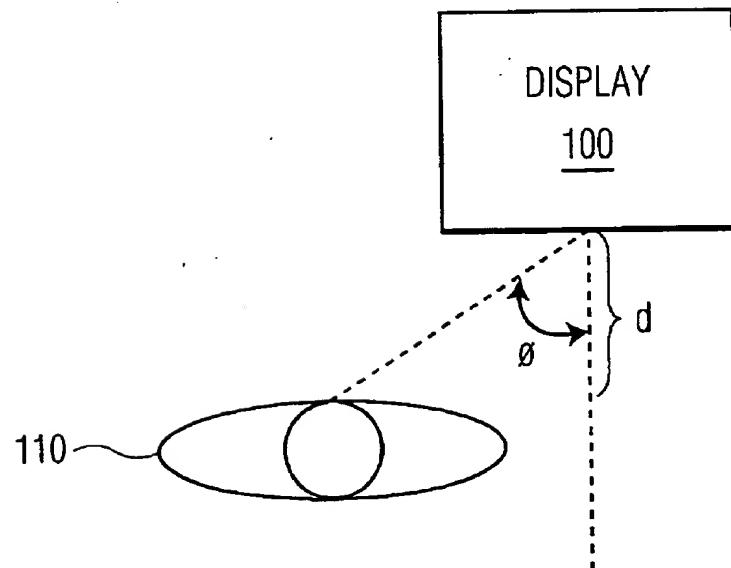
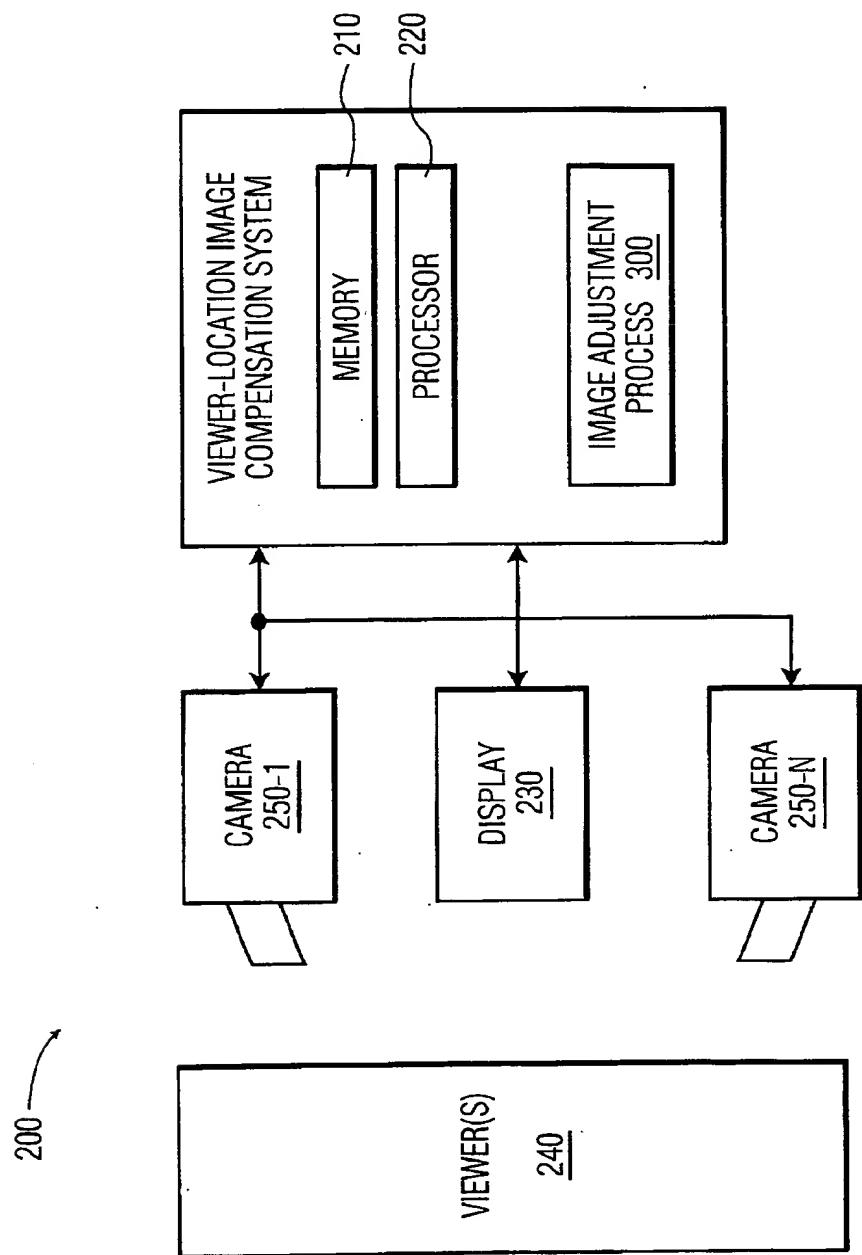


FIG. 1B

**FIG. 2**

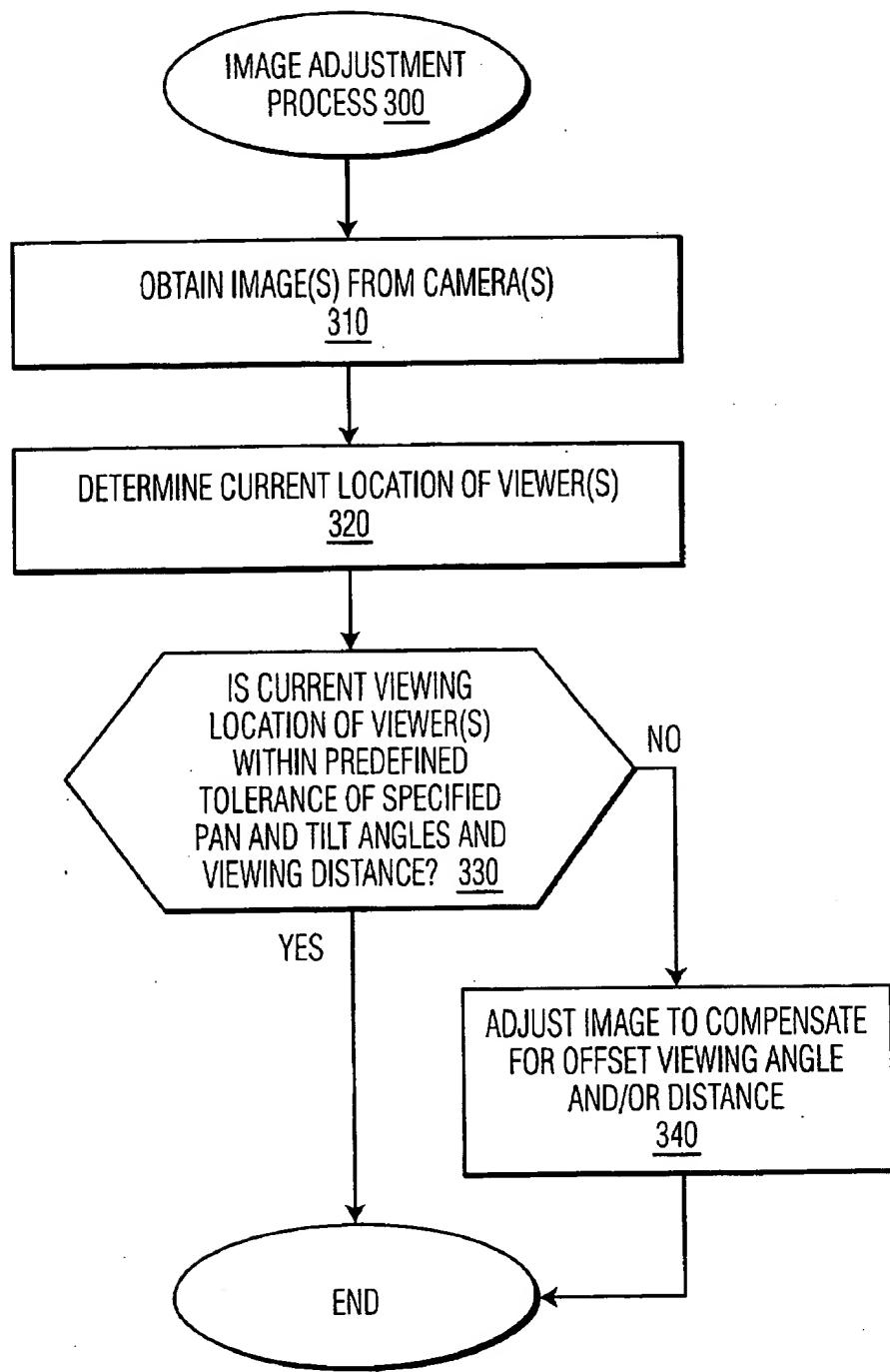


FIG. 3

METHOD AND APPARATUS FOR ADJUSTING AN IMAGE TO COMPENSATE FOR AN OFFSET POSITION OF A USER

FIELD OF THE INVENTION

[0001] The present invention relates to methods and apparatus for controlling a display, and more particularly, to a method and apparatus for automatically adjusting an image to compensate for an offset viewing location of a user.

BACKGROUND OF THE INVENTION

[0002] The consumer marketplace offers a wide variety of devices for displaying images, such as televisions, portable DVD players and computer monitors. Most advances in display technology have been directed to techniques for reducing glare and reflection resulting from light sources and objects located in the vicinity of the display. Typically, image quality is improved by employing polarizing panels or screen coatings (or both) to reduce glare and reflections.

[0003] FIG. 1A illustrates a display 100 that is observed by a viewer 110 from a viewing location defined by a pan angle, Θ , tilt angle, Φ (not shown), and distance, d , relative to the display 100. Display devices are typically optimized for direct viewing by the viewer from a specified viewing distance. In the example of FIG. 1A, the viewer 110 is observing the display 100 from a distance, d , with a direct viewing angle where the pan and tilt angles, Θ and Φ , are approximately zero degrees.

[0004] If the viewer 110 is observing the display 100 from a pan angle, Θ , or tilt angle, Φ , (or both) that is offset from the intended direct viewing angle of the display 100, as shown in FIG. 1B, then the image will appear distorted to the viewer 110. Generally, if the viewer 110 is observing the display 100 from a pan angle, Θ , or tilt angle, Φ , (or both) that is offset from a predefined viewing angle of the display then the portions of the displayed image appearing on the opposite side of the image relative to the viewing location will appear smaller than when viewed from the intended direct viewing angle.

[0005] Similarly, if the viewer 110 is observing the display 100 from a distance, d , that is outside of the optimized viewing range of the display, then the image will likewise appear distorted to the viewer 110. Generally, if the viewer 110 is observing the display from a distance, d , beyond the optimized viewing range of the display 100, then the image will appear smaller to the viewer 110 than when viewed from the intended viewing range. It is further noted that as the size of the display area increases, the distortion caused by viewing the image from an offset position is more significant.

[0006] A need therefore exists for a method and apparatus for adjusting an image to compensate for an offset position of a viewer. A further need exists for a method and apparatus for adjusting an image to compensate for a viewing distance that is outside of an optimized viewing range of a display.

SUMMARY OF THE INVENTION

[0007] Generally, a method and apparatus are disclosed for monitoring the location of one or more viewer(s) and dynamically adjusting the image to compensate for the current location of the viewer(s). In particular, the image is

adjusted to compensate for a viewing location (pan angle, Θ , tilt angle, Φ , or distance, d) outside of a specified range of values. The present invention employs image processing techniques to adjust the input image so that the output image appears as originally intended, for the current viewing location of the viewer.

[0008] According to one aspect of the invention, the disclosed viewer-location image compensation system morphs an image to compensate for an offset pan angle, Θ , or tilt angle, Φ , (or both) to compress portions of the image nearest the viewer and enlarge portions of the image further from the viewer. Likewise, the disclosed viewer-location image compensation system scales an image to compensate for a viewing distance, d , outside of an optimized viewing range of a display ($d < d_{min}$ or $d > d_{max}$).

[0009] In order to compensate for an offset viewing location, the original image can be adjusted using a linear transformation technique to generate a modified image. Generally, the linear transformation maps the pixels in the original image to a new space that distorts the image, such that when the modified image is viewed from an offset viewing location the image appears as if being viewed from a direct viewing location.

[0010] A more complete understanding of the present invention, as well as further features and advantages of the present invention, will be obtained by reference to the following detailed description and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] FIG. 1A is a top view illustrating a viewer observing a display from a direct viewing angle;

[0012] FIG. 1B is a top view illustrating a viewer observing a display from an offset viewing angle;

[0013] FIG. 2 is a schematic block diagram of a viewer-location image compensation system in accordance with the present invention; and

[0014] FIG. 3 is a flow chart describing an exemplary image adjustment process embodying principles of the present invention.

DETAILED DESCRIPTION

[0015] FIG. 1 illustrates a viewer-location image compensation system 200 in accordance with the present invention. As shown in FIG. 2, the viewer-location image compensation system 200 includes one or more cameras 250-1 through 250-N (hereinafter, collectively referred to as cameras 250) that are focused on one or more viewer(s) 240 of a display 230. The images generated by the cameras 250 are utilized to derive the viewing location of a viewer 240 (pan angle, Θ , tilt angle, Φ , and distance, d). The display 230 is any type of image or video display suitable for presenting images to the viewer 240 or for otherwise interacting with a human user, including liquid crystal displays (LCDs), projection systems and displays based on cathode-ray tube technology.

[0016] Generally, the viewer-location image compensation system 200 optimizes the image for the current location of a single viewer 240 or an average location of all viewers 240 in accordance with the present invention. The present invention optimizes an image for an offset viewing location

of a viewer 240, where one or more of the pan angle, Θ , tilt angle, Φ , or distance, d , are outside a specified range of values. In this manner, the present invention employs image processing techniques to adjust the input image so that the output image appears as originally intended, for the current viewing location of the viewer 240.

[0017] According to one feature of the present invention, the viewer-location image compensation system 200 adjusts an image to compensate for an offset viewing angle of a viewer. In particular, as discussed further below in conjunction with FIG. 3, the viewer-location image compensation system 200 morphs an image to compensate for an offset viewing pan angle, Θ , or tilt angle, Φ , to compress portions of the image nearest the viewer 240 and enlarge portions of the image further from the viewer 240. In this manner, the viewer-location image compensation system 200 allows an image viewed from an offset viewing angle ($\Theta \neq 0$ or $\Phi \neq 0$) to appear as if the image is viewed from a direct viewing angle (Θ and Φ approximately equal to 0).

[0018] According to another feature of the present invention, the viewer-location image compensation system 200 adjusts an image to compensate for a viewing distance, d , outside of an optimized viewing range of a display 230. In particular, as discussed further below in conjunction with FIG. 3, the viewer-location image compensation system 200 changes the size of an image to compensate for a viewing location, d , outside of an optimized viewing range of a display 230 ($d < d_{\min}$ or $d > d_{\max}$).

[0019] Thus, if the current viewing distance, d , is greater than the optimized region ($d > d_{\max}$), then the image is enlarged. Likewise, if the current viewing distance, d , is less than the optimized region ($d < d_{\min}$), then the image is reduced. For example, the viewer-location image compensation system 200 can scale the image size to compensate for a viewing distance outside of the optimized viewing region. In an image having textual portions, for example, the size or thickness (or both) of the text can be adjusted. In this manner, the viewer-location image compensation system 200 allows an image viewed from a viewing distance, d , outside of an optimized viewing range of a display 230 to appear as if the image is viewed from a viewing distance, d , within the optimized viewing range of a display 230.

[0020] Each camera 250 may be embodied, for example, as a fixed or pan-tilt-zoom (PTZ) camera for capturing image or video information. The image information generated by the camera(s) 250 are processed by the viewer-location image compensation system 200, in a manner discussed below in conjunction with FIG. 3, to determine the viewing location of a viewer 240. It is noted that a one-camera system can estimate the viewing distance, d , based on the size of the person appearing in the image (assuming a standard size person).

[0021] The viewer-location image compensation system 200 may be embodied as any computing device, such as a personal computer or workstation, that contains a processor 220, such as a central processing unit (CPU), and memory 210, such as RAM and/or ROM. Alternatively, the viewer-location image compensation system 200 may be embodied as an application specific integrated circuit (ASIC) (not shown) that is included, for example, in a television, set-top terminal or another electronic device.

[0022] Memory 210 configures the processor 220 to implement the methods, steps, and functions disclosed

herein. As shown in FIG. 2, the viewer-location image compensation system 200 includes an image adjustment process 300 that is implemented by the processor 220. Generally, the exemplary image adjustment process 300 monitors the location of one or more viewer(s) 240 and dynamically adjusts the image to compensate for the current location of the viewer(s) 240 in accordance with the present invention. The image adjustment process 300 can optimize an image for the current viewing location (pan angle, Θ , tilt angle, Φ , and distance, d) of a viewer 240.

[0023] The memory 210 could be distributed or local and the processor 220 could be distributed or singular. The memory 210 could be implemented as an electrical, magnetic or optical memory, or any combination of these or other types of storage devices. Moreover, the term "memory" should be construed broadly enough to encompass any information able to be read from or written to an address in the addressable space accessed by processor 220. With this definition, information on a network is still within memory 210 because the processor 220 can retrieve the information from the network. It should be noted that each distributed processor that makes up processor 220 generally contains its own addressable memory space.

[0024] FIG. 3 is a flow chart describing an exemplary image adjustment process 300. As previously indicated, the image adjustment process 300 monitors the location of one or more viewer(s) 240 and dynamically adjusts the image to compensate for the current location of the viewer(s) 240 in accordance with the present invention. The image adjustment process 300 may be executed continuously, intermittently or upon a detected movement of a viewer 240, as would be apparent to a person of ordinary skill in the art.

[0025] As shown in FIG. 3, the image adjustment process 300 initially obtains one or more images from the camera(s) 250 during step 310. Thereafter, the image adjustment process 300 determines the location of any viewer(s) 240 that are present during step 320. A test is performed during step 330 to determine if the current viewing location of the viewer(s) 240 is within a predefined tolerance of specified values for each of the pan angle, Θ , tilt angle, Φ , and distance, d .

[0026] If it is determined during step 330 that the current viewing location of the viewer(s) 240 is not within a predefined tolerance of a specified viewing location, then the image is adjusted during step 340 to compensate for the offset viewing angle or distance. An exemplary technique for adjusting the image to compensate for the offset viewing location of the viewer is described below in a section entitled "Image Adjustment Technique."

[0027] If, however, it is determined during step 330 that the current viewing location of the viewer(s) 240 is within a predefined tolerance of a specified viewing location, then program control terminates.

Image Adjustment Technique

[0028] The original image can be expressed as a two-by-two matrix of pixels. In order to compensate for an offset viewing location, the original image is adjusted in an exemplary embodiment of the present invention using a linear transformation technique. Generally, the linear transformation maps the pixels in the original image, I , to a new space

to generate a modified image, M , that distorts the image, such that when the modified image is viewed from an offset viewing location the image appears as if being viewed from a direct viewing location. Thus, a given pixel in the original image can be expressed as P_I and a given pixel in the modified image can be expressed as P_M .

[0029] As previously indicated, the current viewing location is the current location of the viewer's eye, P_e , and is fully defined by the pan angle, Θ , tilt angle, Φ , and distance, d , relative to a fixed point on the display. The current location of the viewer's eye, P_e , can also be expressed as follows:

$$P_e = R \begin{bmatrix} 0 \\ 0 \\ d \end{bmatrix}$$

where $R = \begin{bmatrix} \cos\Theta & 0 & -\sin\Theta \\ \sin\Phi\cos\Theta & \cos\Phi & \sin\Phi\cos\Theta \\ \cos\Phi\sin\Theta & -\sin\Phi & \cos\Phi\cos\Theta \end{bmatrix}$

[0030] In a first embodiment, it is assumed that the user is far away from the display. The distance from the display can thus be ignored. Thus, each pixel in the modified image, P_M , can be obtained by identifying the appropriate index of a corresponding pixel in the original image, P_I . Thus, to obtain a pixel value in the modified image, the appropriate index of the corresponding pixel in the original image, P_I , is identified as follows:

$$P_I = R \cdot P_M = R \begin{bmatrix} x_0 \\ y_0 \\ 0 \end{bmatrix}$$

[0031] Since this embodiment ignores the distance from the display, the corresponding pixel in the original image, P_I , can be expressed as follows

$$P_I = \begin{pmatrix} x_i \\ y_i \end{pmatrix}$$

[0032] In a second embodiment, the distance, d , of the user from the display is considered. Thus, to obtain a pixel value in the modified image, the appropriate index of the corresponding pixel in the original image, P_I , is identified as follows:

$$P_I = R \left(P_M - \frac{\langle P_M, P_e \rangle (P_M - P_e)}{\langle P_e - P_M, P_e \rangle} \right)$$

$$\text{where } P_M = \begin{bmatrix} x_0 \\ y_0 \\ 0 \end{bmatrix}$$

[0033] It is noted that in both the first and second embodiments, if the calculated index of the corresponding pixel in

the original image, P_I , is not an integer value image interpolation is used to obtain the pixel value at the appropriate pixel location.

[0034] As is known in the art, the methods and apparatus discussed herein may be distributed as an article of manufacture that itself comprises a computer-readable medium having computer-readable code means embodied thereon. The computer readable program code means is operable, in conjunction with a computer system to carry out all or some of the steps to perform the methods or create the apparatuses discussed herein. The computer-readable medium may be a recordable medium (e.g., floppy disks, hard drives, compact disks, or memory cards) or may be transmission medium (e.g., a network comprising fiber-optics, the world-wide web, cables, or a wireless channel using time-division multiple access, code-division multiple access, or other radio-frequency channel). Any medium known or developed that can store information suitable for use with a computer system may be used. The computer-readable code means is any mechanism for allowing a computer to read instructions and data, such as magnetic variations on a magnetic medium or height variations on the surface of a compact disk.

[0035] It is to be understood that the embodiments and variations shown and described herein are merely illustrative of the principles of this invention and that various modifications may be implemented by those skilled in the art without departing from the scope and spirit of the invention.

What is claimed is:

1. A method for adjusting an image, comprising:
determining a viewing location of a viewer of said image;
and
adjusting said image to compensate for a viewing location outside a predefined viewing range.
2. The method of claim 1, wherein said viewing location is outside a predefined viewing angle range.
3. The method of claim 1, wherein said viewing location is outside a predefined viewing distance range.
4. The method of claim 1, wherein said adjusting step further comprises the step of mapping pixels in said image to a new image space using a linear transformation that creates a distorted image such that when said distorted image is viewed from an offset viewing location said image appears as if being viewed from a direct viewing location.
5. The method of claim 4, wherein said linear transformation morphs said image to compensate for an offset viewing angle.
6. The method of claim 4, wherein said linear transformation scales said image to compensate for a viewing distance outside said predefined viewing distance range.
7. The method of claim 4, wherein said mapping of pixels to a new image space creates an image with a greater number of pixels using an interpolation technique.
8. A method for adjusting an image, comprising:
determining a viewing location of a viewer of said image;
and
mapping pixels in said image to a new image space using a linear transformation that creates a distorted image such that when said distorted image is viewed from an offset viewing location said image appears as if being viewed from a direct viewing location.

9. The method of claim 8, wherein said viewing location is outside a predefined viewing angle range.
10. The method of claim 8, wherein said viewing location is outside a predefined viewing distance range.
11. The method of claim 8, wherein said mapping morphs said image to compensate for an offset viewing angle.
12. The method of claim 8, wherein said mapping scales said image to compensate for a viewing distance outside said predefined viewing distance range.
13. The method of claim 8, wherein said mapping of pixels to a new image space creates an image with a greater number of pixels using an interpolation technique.
14. A system for adjusting an image, comprising:
 - a memory for storing computer readable code; and
 - a processor operatively coupled to said memory (160), said processor configured to:
 - determine a viewing location of a viewer of said image; and
 - adjust said image to compensate for a viewing location outside a predefined viewing range.
15. The system of claim 14, wherein said processor is further configured to map pixels in said image to a new image space using a linear transformation that creates a distorted image such that when said distorted image is viewed from an offset viewing location said image appears as if being viewed from a direct viewing location.
16. The system of claim 15, wherein said new image space has a greater number of pixels obtained using an interpolation technique.
17. A system for adjusting an image, comprising:
 - a memory for storing computer readable code; and
 - a processor operatively coupled to said memory (160), said processor configured to:

determine a viewing location of a viewer of said image; and

map pixels in said image to a new image space using a linear transformation that creates a distorted image such that when said distorted image is viewed from an offset viewing location said image appears as if being viewed from a direct viewing location.

18. The system of claim 17, wherein said new image space has a greater number of pixels obtained using an interpolation technique.

19. An article of manufacture for adjusting an image, comprising:

- a computer readable medium having computer readable code means embodied thereon, said computer readable program code means comprising:
 - a step to determine a viewing location of a viewer of said image; and
 - a step to adjust said image to compensate for a viewing location outside a predefined viewing range.

20. An article of manufacture for adjusting an image, comprising:

- a computer readable medium having computer readable code means embodied thereon, said computer readable program code means comprising:
 - a step to determine a viewing location of a viewer of said image; and
 - a step to map pixels in said image to a new image space using a linear transformation that creates a distorted image such that when said distorted image is viewed from an offset viewing location said image appears as if being viewed from a direct viewing location.

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